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Cover photo: Arkansas soybean nearly overlapping middles. Photo credit: Kevin Lawson, University of Arkansas System Division of Agriculture, Fayetteville, Ark.

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Preface

The 2017 Arkansas Soybean Research Studies Series includes research reports on topics pertaining to soybean across several disciplines form breeding to post-harvest processing. Research reports contained in this publication may represent preliminary or only a single year of results; therefore, these results should not be used as a basis for long-term recommendations.

Several research reports in this publication will appear in other University of Arkansas System Division of Agriculture's Arkansas Agricultural Experiment Station publications. This duplication is the result of the overlap in research coverage between disciplines and our effort to inform Arkansas soybean producers of the research being conducted with funds from the Soybean Check-off Program. This publication also contains research funded by industry, federal, and state agencies.

Use of products and trade names in any of the research reports does not constitute a guarantee or warranty of the products named and does not signify that these products are approved to the exclusion of comparable products.

All authors are either current or former faculty, staff, or students of the University of Arkansas System Division of Agriculture, or scientists with the United States Department of Agriculture, Agriculture Research Service.

Appreciation is extended to the staff at the state and County Extension offices, as well as the research centers and stations; producers and cooperators; and industry personnel who assisted with the planning and execution of the programs.

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The Arkansas Soybean Promotion Board

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Introduction

Arkansas is the leading soybean-producing state in the mid-southern United States. Arkansas ranked 11th in soybean production in 2017 when compared to the other soybean-producing states in the U.S. The state represents 4.0% of the total U.S. soybean production and 3.9% of the total acres planted in soybean in 2017. The 2017 state soybean average was 51 bushels per acre, a new state record. The top five soybean-producing counties in 2017 were Mississippi, Phillips, Crittenden, Poinsett, and Arkansas Counties (Table 1). These five counties accounted for 36.1% of soybean production in Arkansas in 2017.

Environmental conditions during the 2017 soybean growing season were almost ideal for soybean growth and development, which is reflected by the new State record soybean yield. The early planting progress was ahead of the 5-year average. Many late-season foliar diseases such as aerial web blight, *Cercospora* leaf blight, anthracnose, pod and stem blight, Frogeye leaf spot, and target spot developed late in the season. In addition to late-season disease issues, many fields in the state were treated for several insect pest including corn earworm, other caterpillar species, and stinkbugs. Redbanded stinkbugs were observed in numbers not seen in the State before. Many fields were treated for this pest, with several fields receiving multiple insecticide applications. Some producers reported as much as 20% dockage at elevators due to damage done by Redbanded stinkbugs. Most soybean-producing counties in Arkansas have some level of PPO-resistant Palmer amaranth. Many of these Palmer amaranth populations now have multiple herbicide resistance, and soybean production in these fields is becoming very difficult due to the loss of many herbicides. The 2017 growing season was the first year where the use of dicamba was labeled for over-the-top applications on dicamba tolerant soybean. With this introduction, the Arkansas State

Plant Board received over 1000 complaints from individuals with dicamba symptomology on non-dicamba soybean. These complaints accounted for over 900,000 acres of soybean. Due to the unprecedented number of complaints, the Arkansas State Plant Board elected to ban dicamba application staring on July 11, 2017.

Table 1. Arkansas soybean acreage, yield, and production by County, 2016-2017[a]

	All Planted		Harvested		Yield		Production	
	2016	2017	2016	2017	2016	2017	2016	2017
County	acres		acres		bu/ac		bu/ac	
Arkansas	163,000	187,300	162,800	186,900	54.4	53.7	8,854,000	10,040,000
Ashley	48,400	61,800	48,400	61,400	58.2	56.8	2,819,000	3,490,000
Chicot	143,800	169,700	143,600	168,900	52.7	51.2	7,573,000	8,647,000
Clay	109,100	120,500	107,600	120,100	46.8	54.8	5,035,000	6,583,000
Craighead	107,700	116,700	105,300	115,700	48.8	53.1	5,136,000	6,147,000
Crittenden	202,900	231,300	202,800	230,700	43.7	52.7	8,872,000	12,165,000
Cross	149,800	170,900	149,600	170,200	47.7	51.1	7,133,000	8,696,000
Desha	143,300	176,300	143,300	176,000	55.7	56.7	7,988,000	9,975,000
Drew	33,300	40,400	33,300	40,200	53.5	54.5	1,781,000	2,190,000
Faulkner	7,300	8,600	7,100	8,000	37.2	42.0	264,000	336,000
Greene	67,300	73,800	66,300	73,600	43.8	51.0	2,906,000	3,755,000
Independence	26,900	32,700	24,300	32,500	38.6	43.4	937,000	1,410,000
Jackson	122,400	147,500	121,000	141,000	39.2	42.2	4,745,000	5,949,000
Jefferson	83,700	118,700	83,600	117,500	52.1	53.1	4,359,000	6,240,000
Lawrence	58,400	60,300	55,500	58,800	35.7	42.0	1,981,000	2,467,000
Lee	137,300	148,500	136,700	147,700	43.5	48.5	5,940,000	7,165,000
Lincoln	62,900	77,300	62,800	76,500	56.3	57.8	3,537,000	4,422,000
Lonoke	106,600	121,900	105,900	121,500	46.3	42.5	4,906,000	5,158,000
Mississippi	273,200	291,500	272,900	290,200	48.9	56.7	13,345,000	16,442,000
Monroe	106,000	119,400	105,500	118,500	43.2	47.2	4,561,000	5,597,000
Phillips	213,500	235,100	211,300	233,400	48.9	52.9	10,325,000	12,340,000
Poinsett	179,600	202,700	179,400	202,400	51.0	55.5	9,153,000	11,240,000
Prairie	99,900	108,000	99,400	107,600	50.0	50.9	4,966,000	5,482,000
Randolph	34,400	39,600	29,900	39,400	38.0	48.2	1,135,000	1,900,000
St. Francis	147,000	156,100	145,000	155,000	44.5	49.7	6,458,000	7,703,000
White	35,000	29,700	33,100	27,000	37.9	42.6	1,254,000	1,150,000
Woodruff	115,500	126,000	114,500	123,500	35.7	44.6	4,085,000	5,512,000
Other Counties[b]	40,200	157,700	39,600	155,800	36.7	43.2	1,574,900	6,299,000
State Totals	3,130,000	3,530,000	3,100,000	3,500,000	47.0	51.0	145,700,000	178,500,000

[a]Data obtained from USDA-NASS, 2018.

[b]Benton, Conway, Crawford, Franklin, Lafayette, Logan, Perry, Pope, Pulaski and Yell Counties.

Table of Contents

Irrigation

Soil Fertility

Physiological Characterization of Soybean Nested Association Mapping (SoyNAM) Population Parental Lines for Yield and Drought Associated Traits

A. Mishra[1], L.C. Purcell[1], C. A. King[1], and M.K. Davies[1]

Abstract

The genetic base of soybean (*Glycine max* L. Merr.) in North America is narrow; only 17 accessions contribute to 86% of the parentage of the modern North American cultivars. The Soybean Nested Association Mapping population (SoyNAM) was therefore developed with the objective of diversifying the soybean gene pool. By crossing 40 diverse soybean genotypes from maturity groups (MG) 1 through 5 with a common MG 3 parent, 40 recombinant inbred populations were developed. Each of these populations have 140 recombinant inbred lines (RILs) and have been genotyped with molecular markers and characterized for maturity, nematode rating and a few similar traits. This study focuses on characterizing the parental genotypes of the SoyNAM population for important yield and drought-related traits that have not been previously determined. The experiment was conducted in Fayetteville, Arkansas at the University of Arkansas System Division of Agriculture's Agricultural Research Station with four replications. We measured canopy coverage, the fraction of nitrogen derived from atmosphere (NDFA, measure of N_2 fixation), shoot nitrogen and ureide concentrations, carbon isotope ratio (^{13}C:^{12}C, an indirect measure of water use efficiency), seed growth rate, and seed fill duration. Wilting measurements were taken towards the end of irrigation cycles when drought symptoms started appearing. Yield and harvest index were determined from a bordered section of each plot at maturity. Statistical analysis indicated that several parents differed statistically from the hub parent. Some genotypes were also identified as common extreme parents for more than one desirable trait. Identification of the most divergent parental lines for such traits will aid in selecting recombinant inbred populations for future Quantitative Trait Loci mapping studies.

Introduction

The United States is the world's largest producer of soybean (*Glycine max* L. Merr.), contributing 34% to the world's soybean production. However, the soybean gene pool in North America is quite narrow; only 17 accessions contribute 86% of the parentage to modern cultivars (Carter et al., 2004; Gizlice et al., 1994). This narrow genetic base can limit future yield gains. The Soybean Nested Association Mapping (SoyNAM) population was developed with the objective of diversifying the soybean gene pool and mapping genes associated with important traits affecting yield. Forty diverse soybean genotypes from maturity groups (MG) 1 through 5 were crossed with a common MG 3 parent (IA3023, high-yielding elite cultivar) and 40 recombinant inbred populations were developed. These 40 recombinant inbred populations were genotyped with molecular markers and characterized for maturity, nematode rating, and a few other important traits.

Although several years of research on physiological and biochemical aspects of the crop have provided considerable insight into traits that influence plant growth and crop yield, none of this research has made a significant contribution to cultivar improvement, as it has failed in aiding in problem identification and germplasm selection (Sinclair et al., 2004). The SoyNAM populations, can play a major role in solving this problem and are a tremendous resource that can be utilized to develop a new 'toolbox' for breeders to use. However, the very first step in developing this toolbox is to characterize the parents of the SoyNAM populations.

The current research focuses on characterization of the SoyNAM parental genotypes for yield and drought-related physiological traits. By phenotyping the parental genotypes, it will allow identification of specific mapping populations that will likely have the most segregation for traits of interest. Identification of the most divergent parental lines for these traits will aid in selecting recombinant inbred populations for future Quantitative Trait Loci mapping studies.

Procedures

Experimental Design. Forty-one genotypes (parental lines of SoyNAM project) were planted at the University of Arkansas System Division of Agriculture's Agricultural Research Station, Fayetteville, Arkansas (36°05' N, 94°10' W) on a Captina silt loam soil. In addition to the 41 genotypes (ranging from maturity groups (MG 1 through 5), non-nodulating genotypes (Harosoy (MG 2) and Lee (MG 6)) were

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also included to allow determination of the amount of nitrogen (N) derived from soil and from atmospheric N_2 fixation. The experiment had a randomized complete block design with four replications; each plot consisted of four rows, 30 feet in length with an inter-row spacing of 18 inches, planted on 10 June 2017 at a seed density of 140,000 per acre. The experiment was irrigated using an overhead sprinkler system when the estimated soil-water deficit reached 1.5 inch (Purcell et al., 2007).

Data Collection (Sampling and Processing). Canopy coverage measurements were made twice per week from a drone flown 125 feet above ground level until the canopy closed. These images were processed using software (https://www.turfanalyzer.com/field_analyzer.html) to obtain canopy coverage as an indirect measure of light interception (Purcell, 2000). Shoot samples were taken at the R1 growth stage (Fehr and Caviness, 1977) and used to determine shoot nitrogen concentration, ureide concentration, nitrogen derived from atmosphere (NDFA) and ^{13}C:^{12}C (carbon isotope ratio). Samples were dried, coarsely ground, and a subsample was finely ground and analyzed for total N using the Dumas method with a Leco FP-428 Determinator (Leco Corporation, St. Joseph, Mo.) at the Soil Testing and Plant Analysis Laboratory, University of Arkansas System Division of Agriculture. A similar subsample was used to determine ureide concentration (Young and Conway, 1942). Samples were analyzed for nitrogen (^{15}N:^{14}N) and carbon (^{13}C:^{12}C) isotope composition by University of California Davis Stable Isotope Facility (https://stableisotopefacility.ucdavis.edu/13cand15n.html).

During the linear phase of seed filling, four random plants were harvested at ground level at mid-R 5 and then again after 7-10 days, and used to obtain average seed weight (g/seed) and seed growth rate (SGR, g/seed d). Seed fill duration (SFD) was estimated as the quotient of the average seed weight at maturity and SGR (Daynard et al., 1971). A final sample was taken at physiological maturity to determine harvest index.

Infrared images were made once the canopy was closed using a drone mounted with an infrared camera (FLIR Tau 640, Goleta Calif.), flown above the canopy at a height of 400 feet. The average value of pixels within each plot was determined with software (https://www.turfanalyzer.com/field_analyzer.html) and used as a measure of relative canopy temperature (Bai and Purcell, 2018) towards the end of an irrigation cycle when there were visible drought symptoms. Wilting measurements were also made during this time when there was sufficient moisture deficit, using a visual scale from 0 (no wilting) to 100 (dead plants) (King et al., 2009). Yield was determined from a bordered section (12 feet) of each plot at maturity.

Statistical Analysis. The data were analyzed using the Glimmix procedure in SAS 9.4 (SAS Institute, Cary, N.C.). Maturity group and genotypes nested within MG were fixed effects, and replications were treated as random effects. Canopy coverage was analyzed as a repeated measure (as measurements were taken multiple times during the season) with stand counts as a covariate.

Results and Discussion

The analysis of variance results (Tables 1 and 2) showed that most traits had a significant MG effect, except for nitrogen concentration, NDFA, canopy temperature, and seed weight. For most traits, genotypes differed significantly, but there were no significant differences among genotypes for canopy temperature.

Seed growth rate and SFD showed a strong negative correlation (r = -0.84), indicating that genotypes with high SGR tend to have a shorter seed filling period (Table 3). Seed fill duration and yield had a positive correlation (r = 0.40), while SGR and yield had a negative correlation (r = -0.50), indicating that genotypes with a slow SGR and a long SFD tend to have higher yield and vice-versa. Previous literature has also identified the association of SFD with yield (Dunphy et al., 1979; Smith and Nelson, 1986). Canopy coverage and yield and canopy coverage and SFD were both positively correlated (r = 0.42 and r = 0.34, respectively). Carbon isotope ratio and canopy coverage were positively correlated (r = 0.40), indicating that higher water use efficiency may have led to higher yield.

Practical Applications

The present research evaluated the 41 parental SoyNAM genotypes for different physiological traits important with respect to yield and drought. Once the genotypes that are extremes for each of these traits are identified, the next step will be to map the trait in the corresponding recombinant inbred population.

Acknowledgements

The funding of this research from the Arkansas Soybean Promotion Board and the United Soybean Board is gratefully acknowledged by the authors, as well as the support provided by the University of Arkansas System Division of Agriculture.

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Table 1. Analysis of variance for seed growth rate (SGR), seed fill duration (SFD), seed yield (SDYLD), harvest index (HI), seed weight (SDWT), and canopy coverage (CC) evaluated on the SoyNAM parental genotypes for the effect of maturity group (MG) and genotypes nested within maturity group.

	MG		Genotype (MG)	
	DF	*P*-value	DF	*P*-value
SGR	4	<0.0001	36	<0.0001
SFD	4	<0.0001	36	<0.0001
SDYLD	4	<0.0001	36	<0.0001
HI	4	<0.0001	36	<0.0001
SDWT	4	0.6289	36	<0.0001
CC[a]	4	<0.0001	36	<0.0001

[a]Analyzed as repeated measures.

Table 2. Analysis of variance for nitrogen concentration (NC), nitrogen derived from atmosphere (NDFA), ureide concentration (UC), wilting (WLT), canopy temperature (CT), and carbon isotope ratio (^{13}C:^{12}C) evaluated on the SoyNAM parental genotypes for the effect of maturity group (MG) and genotypes nested within maturity group.

	MG		Genotype (MG)	
	DF	*P*-value	DF	*P*-value
NC	4	0.672	36	0.010
NDFA	4	0.136	36	0.016
UC	4	<0.0001	36	<0.0001
WLT[a]	4	0.004	36	<0.0001
CT	4	0.657	36	0.944
^{13}C:^{12}C	4	0.012	36	0.001

[a] Days after growth stage R1 was used as a covariate.

Table 3. Correlation matrix for seed growth rate (SGR), seed fill duration (SFD), seed yield (SDYLD), ureide concentration (UC), seed weight (SDWT), harvest index (HI), nitrogen concentration (NC), canopy coverage (CC), wilting (WLT), canopy temperature (CT), nitrogen derived from atmosphere (NDFA), and carbon isotope ratio (^{13}C:^{12}C) evaluated on the SoyNAM parental genotypes.

	SGR	SFD	SDYLD	UC	SDWT	HI
SGR	1					
SFD	-0.84**	1				
SDYLD	-0.50**	0.40*	1			
UC	-0.01	0.04	0.36*	1		
SDWT	0.29	0.15	-0.20	0.12	1	
HI	-0.11	-0.06	0.13	0.37*	-0.02	1
NC	0.07	-0.06	-0.01	0.44**	0.13	0.46**
CC	-0.11	0.34*	0.42**	0.45**	0.19	-0.22
WLT	-0.08	0.03	0.35*	0.26	-0.02	0.18
CT	-0.14	0.21	-0.03	0.05	0.01	-0.06
NDFA	-0.10	0.10	0.25	0.28	-0.12	0.05
^{13}C: ^{12}C	-0.01	0.12	0.31*	0.38*	0.28	0.05

	NC	CC	WLT	CT	NDFA	^{13}C: ^{12}C
NC	1					
CC	-0.11	1				
WLT	0.15	0.16	1			
CT	-0.09	0.04	-0.06	1		
NDFA	0.11	0.54**	0.19	0.04	1	
^{13}C: ^{12}C	0.05	0.40**	0.21	0.41**	-0.04	1

***, ** indicate significance at *P* = 0.05 and 0.01 levels, respectively.**

Using Leaf Surface Temperature to Identify Salt Stress in Soybean Genotypes

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Abstract

When soybean, *Glycine max* (L.) Merr., plants are exposed to harmful levels of salt in the soil, they can respond by decreasing rates of water loss through their leaves. This results in increased leaf surface temperatures, due to a decrease in evaporative cooling. Because accumulation of chloride (Cl^-) in Arkansas soils continues to impact soybean production, we set out to test whether non-destructive measurement of leaf temperature could visualize differences among cultivars with varying levels of tolerance to salt. Infrared reflection from leaves demonstrated differences between a Cl^--includer and Cl^--excluder treated with high levels of salt. The differences occur well before visible changes such as curling and browning in leaves.

Introduction

High levels of Cl^- salts in irrigation water and soils can negatively affect the yield potential of many crops. Salt-affected soils are increasing worldwide, with soluble ions sodium (Na^+) and Cl^- being among the most harmful to plants (Munns and Tester, 2008). In Arkansas, soils irrigated with groundwater carrying high Cl^- concentrations are prone to buildup of harmful salts. Salt tolerance among soybean varieties can vary greatly, and is generally based on the plant's ability to prevent uptake of Cl^-. Salt-sensitive soybean varieties are often known as Cl^--includers; whereas Cl^--excluders tend to be more tolerant to the effects of salts. In research and breeding to select for Cl^--excluders, researchers often use the destructive methods of measuring Cl^- in leaves, or waiting until symptoms of salt damage such as leaf curling and death occur. Therefore, development of a rapid and non-destructive test for salt tolerance could be an improvement on current methods.

In response to drought and salt stresses, plants close the leaf pores called stomata that are ultimately responsible for regulating water and gas exchange (Davies et al., 2005). Reducing stomatal conductance prevents water loss but also reduces gas exchange and overall water transpiration, thus the plant will suffer decreased metabolism when exposed to salt. By reducing the amount of water loss via stomata, salt stress can result in an increase in leaf surface temperature.

Infrared thermography is commonly used to assess crop health (Sirault et al., 2009), and has been used to demonstrate a correlation between stomatal closure and high plant temperature (Jones, 1999). Our goal here was to determine if we could detect differences in leaf temperatures and stomatal conductance in known Cl^--includers and Cl^--excluders treated with salt.

Procedures

Soybean cultivars Clark (salt-sensitive) and Manokin (salt-tolerant) were planted into 10.2- by 10.2- by 8.9-cm plastic pots with pasteurized river sand at a density of four seeds per pot. Lines were used because they are U.S. varieties categorized as Cl^--includer and -excluder, respectively. Treatments began when the first trifoliate was fully emerged (V1 stage), and were repeated daily as partial flooding with 100 mM NaCl or deionized H_2O for two hours.

Plants were imaged with a FLIR T420 infrared camera inside of a studio light box (Cowboy Studio, Allen, Texas) to diffuse incoming light. Two sheets of amber-colored plexiglass served as a background (Sirault et al., 2009). Average temperature was measured for each of the three leaflets of the first (oldest) trifoliate from which the average temperature for each plant was calculated. Seven plants of each cultivar were analyzed for both the H_2O and NaCl treatments. Temperature response was calculated by subtracting the average temperature of H_2O-treated plants from the average temperature of NaCl-treated plants of the same cultivar, recorded for six days. Average differences between the cultivars were compared by Student's *t*-test at $P < 0.05$. Stomatal conductance was measured with a leaf porometer, on the same plants treated as described above. Means were compared using one-way analysis of variance with Tukey's post hoc test at $P < 0.05$.

Results and Discussion

Following daily water or NaCl treatments, infrared thermographs were captured of seven plants of each cultivar and treatment. The average leaf surface temperatures were calculated and the difference between water- and NaCl-treated plants was used to determine the effect of salt treatment. Throughout the treatment period, NaCl-treated Manokin plants showed a temperature difference of 0.5 °C or less compared to water-treated plants (Fig. 1), indicating that salt-tolerant Manokin plants responded to NaCl with a small increase in temperature. The temperature difference for Clark plants ranged from about 0.2 to 1.2 °C between treatments, and was significantly higher than the temperature dif-

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ference for Manokin plants on day 3 of the treatment (Fig. 1). This data also show that the salt-sensitive line suffered from larger leaf temperature increases earlier in the treatment period. The insignificant and delayed increase in leaf temperature seen in salt-tolerant Manokin plants indicates that these plants are able to maintain relatively normal transpiration levels under stress. Comparatively, salt-sensitive Clark plants experienced larger increases in temperature under salt stress. The decrease in leaf temperature differences on day 6 in Clark plants was probably due to severe salt-stress symptoms at that stage.

To determine whether the observed temperature differences could be due to a difference in water transpiration, we measured stomatal conductance of the same plants used in for infrared imaging. Stomatal conductance was determined with a leaf porometer following three days of treatments. The stomatal conductance of both cultivars was significantly reduced due to NaCl-treatment (Fig. 2). In water-treated control plants, stomatal conductance of salt-sensitive Clark is higher than salt-tolerant Manokin (Fig. 2). Taken together, the data show that overall changes of transpiration are less in Manokin, as indicated by the lower ratio of difference between water and NaCl effects.

These preliminary findings show that non-destructive measurements of leaf temperature and stomatal conductance can be used to differentiate between Cl^--includer and Cl^--excluder lines of soybean. Importantly, these changes can be measured much earlier than visible leaf damage due to salt stress.

Practical Applications

The results suggest that infrared thermography might be a valuable tool in distinguishing between plants that are sensitive or tolerant to high levels of salt. Infrared detection has been widely used via remote sensing to identify plants or fields suffering from water deficit. This small-scale approach might also be useful in identifying plants or genetic lines that vary in their responses to stress, which could be a useful tool for breeding programs and agronomic studies.

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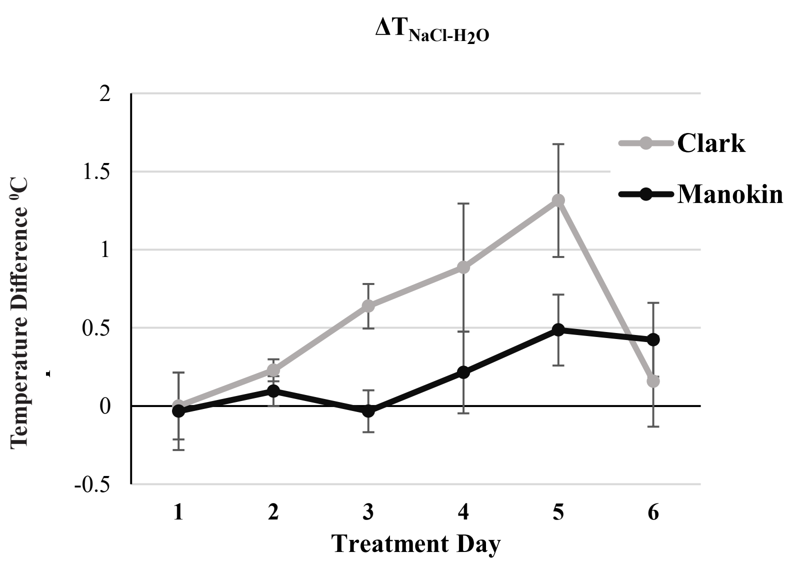

Fig. 1. The temperature difference between NaCl- and H_2O-treated plants in chloride-includer Clark and chloride-excluder Manokin over six days of 100 mM NaCl treatment. This increase in temperature due to NaCl treatment is only significantly different from Manokin on day 3 of the treatment according to Student's *t*-test; n = 7; error bars indicate + SEM; $P < 0.05$.

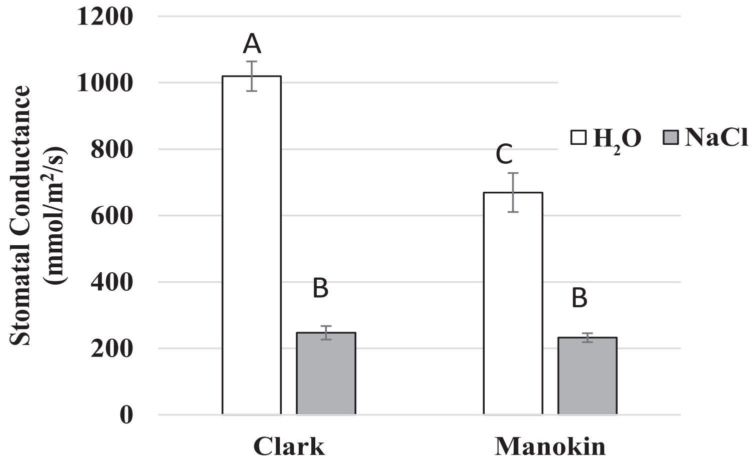

Fig. 2. The stomatal conductance of NaCl- and H_2O-treated Clark and Manokin soybean following three days of salt treatment. Groups with the same letter are not statistically different from each other (analysis of variance; error bars indicate + SEM; n = 10; *P* < 0.05).

Soybean Plant Sap Flow in High Water Demand and Final Growth Stages

M. Ismanov[1], C. Henry[2], L. Espinoza[3], and P. Francis[4]

Abstract

The study of soybean water relations in actual field conditions will improve irrigation management decisions and efficiency. A study initiated in 2017 at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station near Marianna, Ark. determined the relationships between soybean (*Glycine max.*, L. Merr) sap flow, soil moisture, evapotranspiration (ET), and weather from seed fill to maturity. Maximum sap flow occurred in the middle of July (R5 growth stage) and slowly decreased toward the end of July until the middle of August (R6-R6.5), then sharply decreased until the end of August (R7). Sap flow measurements were highly correlated with ET and soil moisture content. Sap flow increased after every irrigation and rainfall event, quickly reaching a maximum level and then decreasing. This cycle of sap flow surge with added water continued until the end of the season. Average sap flow of soybean plants, measured at the R5 growth stage, is relatively high at 361 g/day per plant or 0.29 in./day per acre, coinciding with peak leaf area index (LAI) of 3–3.6. The data reveal soybeans may need supplemental irrigation from R6.5 to R7 for optimum yields, depending on soil moisture and weather conditions.

Introduction

Understanding soybean response to soil moisture content and weather conditions, especially in high moisture demanding late seed fill growth stages, will improve irrigation efficiency and irrigation-termination decisions. The water demand of a soybean plant depends on growth stage and weather conditions. In every moment of the plant's life, plant nutrients in the soil water enter the root system and move to the stem, leaves, and pods. Hydraulic gradients created by micro capillaries of xylem and phloem tissue, osmotic potentials due to photosynthesis production in leaves, and leaf transpiration drive the transport of water and plant nutrients from the soil solution. Soil water resistance and hydraulic conductance of the plant regulate the magnitude of sap flow. Hydraulic conductance is a major barrier to water flow in the soybean plant as it is not flow dependent (Moreshet et. al., 1990). Studies to determine sap flow characteristics in relation to soil water resistance, growth stages, and weather conditions will improve irrigation management efficiency.

Transpiration rates of soybean and maize (*Zea mays*, L.) declined rapidly at high soil matric potential, and then slowly decreased as the soil dried in controlled growth chamber studies (Cohen et. al., 1990). Although transpiration rates declined by nearly 30% following a reduction of soil matric potential to -0.1 MPa, differences in leaf water potential and CO2 assimilation rate were small, as resistance to water flow increased as the soil dried. Studies to document these relationships, under actual field conditions, at critical yield-producing (seed fill) growth stages is of utmost importance.

Soil moisture, solar radiation, air temperature and vapor pressure deficit have a significant influence on sap flow on tomato plants (Guangcheng et al., 2016). The diurnal variation of sap flow showed a single peak curve on sunny days and an irregular, multi-peak variations on rainy days. Various methods of measuring plant water use and sap flow have been utilized such as stomatal conductance (Smith and Allen, 1996), plant chambers (Golden and Field, 1994), lysimeters (Rana and Katerji, 2000; Ismanov et. al., 2015), and field water balance and thermal methods (Smith and Allen, 1996). Stem sap flow measurement, using electric heaters and temperature sensors, is a relatively accurate and easy method to use under field conditions.

The objective of these studies is to document sap flow and soybean water use at different growth stages, particularly during late seed fill growth stages, using stem sap flow sensors under field conditions. Results from these studies will improve soybean irrigation management by more accurately predicting soybean water use, and date of irrigation-termination, under the specific weather and soil conditions of Arkansas.

Materials and Methods

Soybeans (Dyna-Gro 39RY43) were planted on 19 April 2017 at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station near Marianna, Ark. The crop was grown according to recommendations of the University of Arkansas System Division of Agriculture's Cooperative Extension Service. Soybeans were planted in 38-inch wide-row spacing, with an intended population of 109,000 plants/acre. Potential evapotranspiration (ETp) was recorded hourly using atmometers (ETgage Company, Loveland, Colo. www.etgage.com) installed next to the plots. The soil moisture profile (cbars) was recorded hourly with Watermark® soil moisture sensors installed at 6, 12, 18,

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and 30 inches and Irrometer® 900M data logger (Irrometer Compant, Riverside, Calif.) (http://www.irrometer.com/). Additionally, gravimetric soil moisture was measured weekly to a depth of 36 inches in 6-inch increments. Equations obtained good correlation of gravimetric soil moisture and water content in different soil layers throughout the soybean vegetation period used to calculate soil water balance. Soil water was determined by:

$$W_n = \sum_{i=1}^{n} S_{mi} * \sigma_i * H_i / 100$$

Where, W_n – Amount of water at from 1 to n layers of soil; S_{mi}– Soil moisture in different depth intervals (%); H_i - Height of soil depths intervals (inches); and σ_i – Soil bulk density (lb/inch^3).

Soil temperature was recorded at 1 and 6 inches depth with iBWetL® (Alpha Mach, Sainte-Julie, Qc. Canada) (www.alphamach.com) and leaf, pod, and stem temperature measured by infrared thermometer daily (Cen-Tech IRT). Plant height and width, number of nodes, number of leaves, and stem diameter were measured on a weekly basis. Plant leaf and pod areas, and plant moisture content were recorded at reproductive growth stages. Weather parameters were recorded with a WatchDog 2900 ET® Weather Station (Spectrum Technologies, Aurora, Ill. www.specmeters.com).

SGB-9 WS® sap flow sensors (Dynamax Inc., Houston, Texas. www.dynamax.com) were installed when the stem diameter of the soybean plants reached the available sensor diameter (8 or 9 mm). The Flow32-1K® system is supplied with data logger, multiplexer for up to 8 Dynagages® sap flow sensors and AVRD (a dual adjustable voltage regulator) for supplying sensor heater voltage. The instruments were contained in a weatherproof enclosure (Fig. 1). Each system was secured with pigtail cables for sap flow sensors and powered with an AlDelco 86 AH Marine Battery and solar charger panel (Campbell Scientific, Logan, Utah. www.campbellsci.com). Sap flow sensors were installed about 8-10 inches above the soil surface and wrapped with several layers of insulation to keep the heat energy in the plant stem (Fig. 2). Sensors were equipped with a heater and temperature sensors that recorded upcoming and outgoing sap stream temperatures. Sap flow amount was measured in 10-minute intervals. Daily sap flow (S) of individual plants was calculated as follows:

$$S = \frac{0.061mn}{6273000}$$

Where, m is average sap flow for several plants (g); and n is the plant density (plants/acre).

Results and Discussion

Sap flow, irrigation, rainfall, and evapotranspiration in 2017 varied with date and time (Fig. 3). Maximum sap flow occurred in the middle of July (R5 growth) and slowly decreased toward the end of July until 17 August (R6-R6.5), then sharply decreased until the end of August (R7). Sap flow in September was relatively steady at roughly 7X less than the maximum sap flow rates measured in July. The data revealed small sap flow occurring into R8 growth stage when soybean stems become almost dry and brown with a few pods with light green areas.

Sap flow was highly correlated with ET and soil moisture content, particularly in July-August (Figs. 4 and 5). Increases in ETp demand, as measured by the atmometers, up to 0.3 inch/day may cause slight, 0-15%, decreases in sap flow. Sap flow values indicated that plant water use was around 1.3 times greater than ETp in the middle of July, decreasing to around 1 from the middle of July to the middle of August, and then dropping to around 0.25 ETp thereafter. Sap flow increased after every irrigation and rainfall event, quickly (in 1 or 2 days) reaching a maximum level and then slowly decreasing (4-5 or more days). This cycle of sap flow surge continued until the end of the season. Sap flow also increased with soil moisture.

Preliminary measurements show that the daily contribution of sap flow to plant biomass is approximately 0.5-0.8% of sap flow rate during R5 growth stage, and 0.8-1.2% during R6 growth. Average sap flow of soybean plants, at the R5 growth stage, is relatively high at 361 g/day per plant or 0.29 inch/day per acre, and LAI of the plants also peaks at 3–3.6 (Table 1). Accumulated ET during R5 was 4.06 inches, while accumulated sap flow was 5.27 inches During the R6 growth stage, the plant water demand was about half at the R5 growth stage and average water use was 0.14 inch/day. From growth stages R6.5 to R7, daily sap flow decreased from 0.18 to 0.07 in./day, and the ratio between sap flow and ET from 1.12 to 0.4. The data reveal soybeans may need supplemental irrigation from R6.5 to R7 depending on soil moisture and weather conditions. After R7, sap flow averaged 0.03 in./day in R7, and 0.02 in. per day in R8 growth stages.

Practical Application

Our preliminary observations show that soybean growers should intensify their irrigation management efforts during R5 growth stage, when moisture demand and sap flow is highest, and continue these efforts up to R7. The sap flow data reveal that significant moisture demand and seed gains continue until R6.5 and then gradually decline until R8. High correlations between soil moisture and sap flow verify the importance of using soil moisture sensors, in addition to other tools such as atmometers and crop ET prediction models, for precise irrigation scheduling.

Acknowledgments

This project is funded by the Arkansas Soybean Promotion Board and the University of Arkansas System Division of Agriculture.

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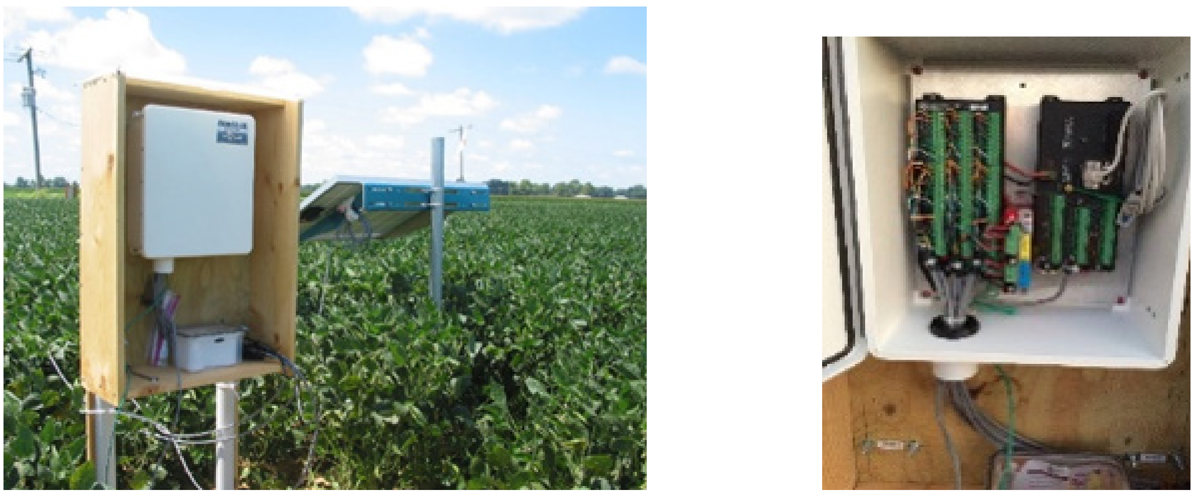

a   b

Fig. 1. Flow32-1K sap flow system (a) and dual adjustable voltage regulator with CR-1000 data logger (b).

Fig. 2. Installation of sap flow sensor in soybean plant stem.

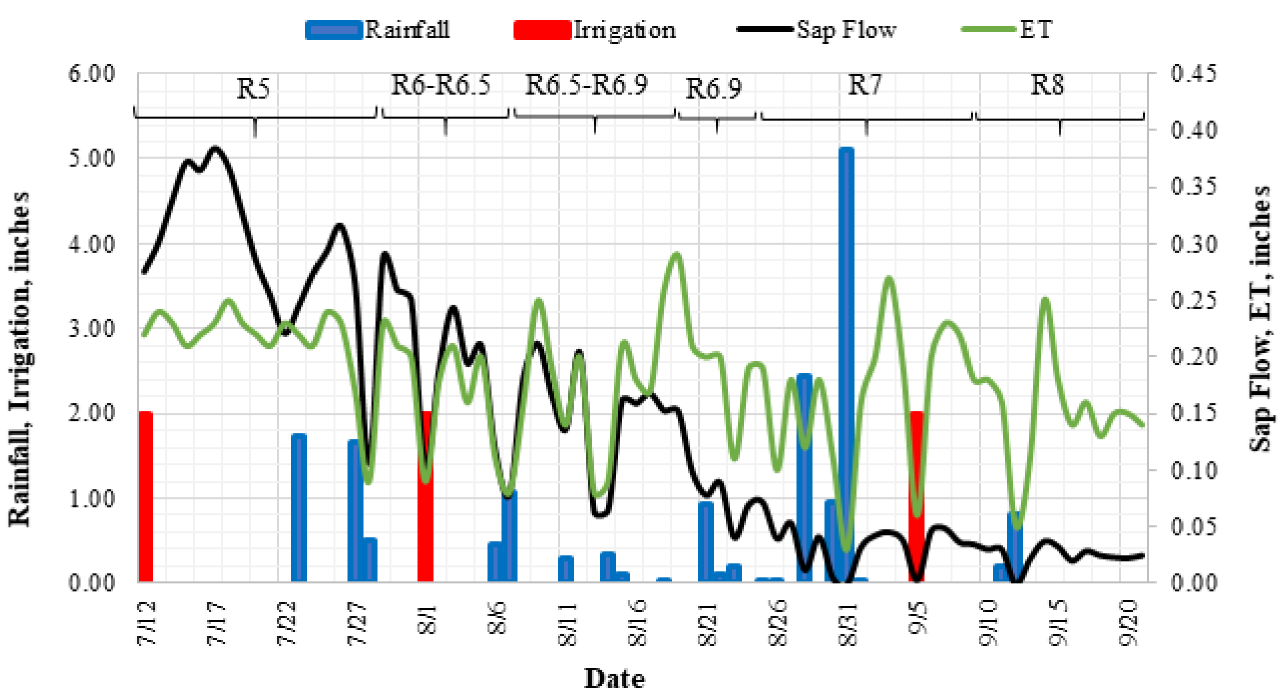

Fig. 3. Daily average sap flow, rainfall, irrigation, and evapotranspiration (ET) in final growth stages of soybean plants.

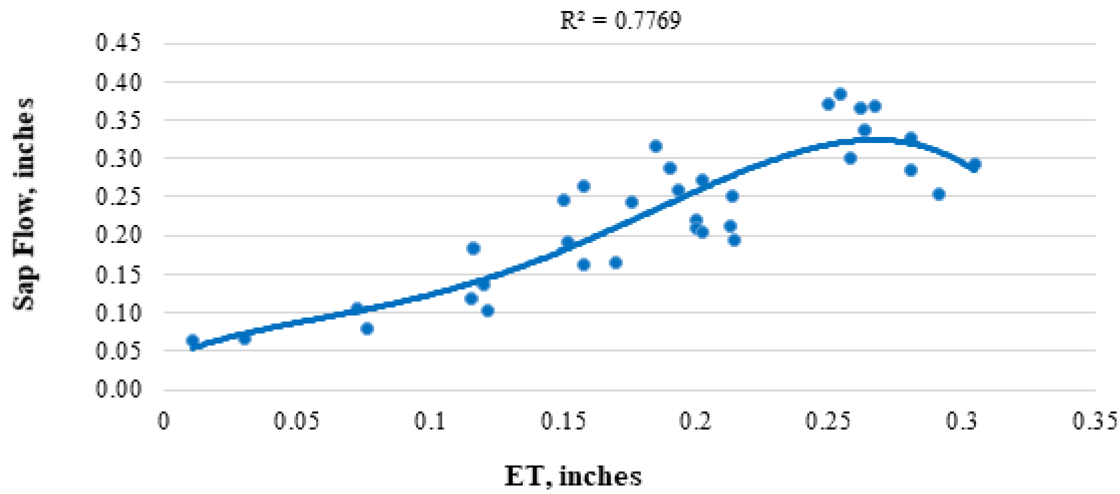

Fig. 4. Correlation between sap flow and evapotranspiration (ET).

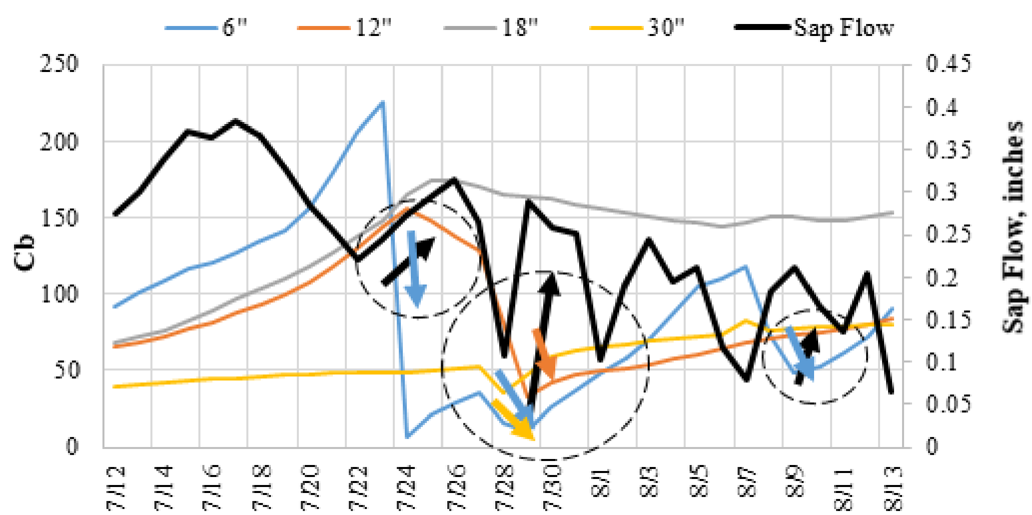

Fig. 5. Watermark (in centibars, Cb) or soil moisture impact to the plant sap flow.

Table 1. Soybean water need in different growth stages.

Plant growth stages		Days to maturity	Water needed to end of season	Daily water need	Ratio of sap flow to evapotranspiration
			-------------inches------------		
R5	Beginning of seed enlargement	40	10.0	0.29	1.30
R6 – R6.5	End of seed enlargement to leaves beginning to yellow	30	4.71	0.18	1.12
R6.5 – R7	Leaves begin to yellow	20	1.64	0.10	0.60
R7	Beginning maturity	10	0.75	0.03	0.22
R8	Maturity	0	0.27[a]	0.02[a]	0.14

[a] Plants still uptake water from the soil due to micro capillarity and evaporation.

Breeding New and Improved Soybean Cultivars with High Yield and Disease Resistance

L. Mozzoni[1], M. Orazaly[1], L. Florez-Palacios[2], P. Manjarrez-Sandoval[2], C. Wu[2], and P. Chen[3]

Abstract

The focus of the University of Arkansas System Division of Agriculture's Soybean Breeding and Genetics Program is developing maturity group (MG) 4 and 5 soybean varieties with high yield, pest resistance, and specialty traits. More emphasis has been given recently to developing MG 4 cultivars to meet the demands of Arkansas farmers. Conventional and glyphosate-tolerant cultivars developed in our soybean breeding program are well adapted to Arkansas and other southern states. We select high-yielding lines from various public breeding programs to design new cross combinations every year. Each year new crosses are made, breeding populations are advanced, and selections are made for progeny rows, preliminary yield trials, and advanced yield trails in Arkansas. Our most advanced promising lines are evaluated in the United States Department of Agriculture's (USDA) Uniform Preliminary Test, USDA Uniform Test, and Arkansas and other southern states' variety testing programs. In 2017, we licensed two cultivars, UA 5115C and UA 5615C, and submitted a release proposal for a high-yielding high protein line, R11-7999.

Introduction

High yield, pest resistance, good adaptation, as well as seed composition and disease traits are the main targets when we develop new cultivars at the University of Arkansas System Division of Agriculture's Soybean Breeding Program. We evaluate potential releases for various years in multiple Arkansas locations and other southern states. They are also tested in the Arkansas Soybean Performance Testing program as well as other Official Variety Testing (OVT) programs in the south. The best yielding lines across locations with good disease package and the trait of interest are selected for release. Potential releases are usually checked for soybean cyst nematode (SCN), root knot nematode (RKN), sudden death syndrome (SDS), stem canker (SC), frogeye leaf spot (FLS), and soybean mosaic virus (SMV) in addition to flood and salt tolerance.

Our lines have relative maturity of late 4 to late 5. More effort is being made toward breeding mid maturity group (MG) 4 soybeans, and our addition of a winter nursery in Chile is expediting the development process. Most of our released cultivars such as Osage (Chen et al., 2007), Ozark (Chen et al., 2004), UA 5612 (Chen et al., 2014a), UA 5213C (Chen et al., 2014b), UA 5014C (Chen et al., 2016), UA 5814HP (Chen et al., 2017), and UA 5615C have been used in commercial production and cultivar development in other breeding programs. Osage and UA 5612 have been used as yield checks in the United States Department of Agriculture (USDA) Uniform tests.

Procedures

The objective of the project is to combine the best traits from different varieties and/or lines. The breeding scheme can be summarized as: 1) identifying and selecting high-yielding parents with desired complementary traits and intercrossing them, 2) advancing breeding populations for three to four generations to allow genetic segregation/recombination, and 3) selecting best performing lines with the traits and evaluating them in multi-location tests for multiple years. The process is cyclical, and any given year is a snapshot of breeding activities at various stages of development.

In 2017 we made a total of 137 different cross combinations for several projects using high-yielding lines with special seed composition traits, and/or disease-resistant germplasm developed from the University of Arkansas breeding program and other public breeding programs. The plant populations at early generations were advanced using a bulk-pod descent method, and 7746 $F_{4:5}$ progeny rows were evaluated for adaptation and agronomic performance. Off-season nursery facilities are used to speed up the breeding process. The preliminary yield trials were tested in two Arkansas locations in non-replicated tests. Advanced yield trials were tested in three Arkansas locations with three replications.

The best advanced lines were selected and evaluated in the USDA Southern Uniform Tests and the Arkansas Soybean Variety Performance Tests. Promising lines were increased for foundation seed in preparation for cultivar release. Advanced lines entered in USDA yield trials and Arkansas

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Soybean Variety Performance Tests were also included in a cooperative test for SCN, RKN, SDS, SC, SMV, and FLS in other southern state programs.

Results and Discussion

In 2017, we licensed two high-yielding conventional cultivars, UA 5115C (formerly R09-430) and UA 5615C (formerly R10-230). These lines were ranked 1st and 2nd when evaluated in the multi-state USDA trails for two years. Cultivar UA 5115C is a maturity group 5.1 and the seed contains 42.3% protein and 22.6% oil on a dry weight basis. Cultivar UA 5115C is resistant to stem canker and frogeye leaf spot and is moderately resistant to root-knot nematode and sudden death syndrome. Cultivar UA 5615C is a maturity group 5.6 and the seed contains 40.5% protein and 22.3% oil on a dry weight basis. Cultivar UA 5615C is resistant to stem canker and frogeye leaf spot. It is moderately resistant to reniform nematode.

We produced foundation seed for our previously released conventional cultivars: Osage (31 acres), UA 5612 (50 acres), UA 5213C (70 acres), and UA 5014C (24 acres) and Roundup Ready® (RR) cultivars UA 5414RR (164 acres) and UA 5715GT (50 acres). Pre-Foundation production consisted of eight promising cultivars as future releases and/or licenses.

A new high-protein and high-yielding cultivar, R11-7999, is proposed to the committee to be released and licensed. It has 44.3% protein on dry weight basis and yields the same as commercial checks on average in multi-year tests across 26 environments. In 2017, R11-7999 was tested in seven states' variety testing programs (Ark., Tenn., Miss., Ga., La., N.C., and Ala.) and yielded between 52.3 and 70 bu/ac which was 84% to 100% of the test mean. In addition, we have submitted 19 lines which are releases or potential releases to be evaluated in multi-state variety testing trials. Our lines were compared with commercial checks, along with elite lines from other public breeders and private companies. These lines were tested in Arkansas, Kansas, Kentucky, Virginia, Tennessee, Mississippi, North Carolina, South Carolina, Georgia and Louisiana. For potential releases, we put more emphasis on the Arkansas Variety performance testing results. Six of our potential releases, R13-13997, R12-712, R11-328, R12-226, R13-13433, and R13-1019, yielded between 61.8 and 67.6 bu/ac which was 87% to 95% of the test mean in the 2017 University of Arkansas variety testing program for MG late 4 to mid 5.

A total of 13 and 22 advanced high-yielding lines were in the 2017 USDA Southern Regional Uniform and Uniform Preliminary Tests, respectively (Table 1). Those 13 lines in the Uniform test yielded between 50.4 and 65.1 bu/ac. Two lines in MG 5 test, R13-4638RY and R13-13997, were ranked 1st and 2nd with 65.1 and 64.6 bu/ac yield, respectively. Our 22 lines in the Uniform Preliminary test yielded between 45 and 62.6 bu/ac. In the MG 5 late test, R11-8346 was ranked 4th with 57.6 bu/ac yield.

A total of 1350 lines were evaluated in advanced and preliminary yield trials in Arkansas in 2017, with approximately 10% of entries being MG 4 and 90% MG 5 (Table 1). These entries included: 70 advanced and 255 preliminary conventional lines; 15 advanced and 135 preliminary RR lines; 30 advanced and 90 preliminary Roundup Ready 2 Yield® lines; 30 advanced and 30 preliminary genetically diverse lines; 25 advanced and 15 preliminary drought-tolerant lines; 30 advanced and 75 preliminary disease-resistant lines; 25 advanced and 30 preliminary high protein; 35 advanced and 45 preliminary high oil lines; 70 advanced and 285 preliminary modified fatty acid (low linolenic, low sat, and/or high oleic) lines, 15 advanced and 45 preliminary high sugar lines. Also, a total of 1643 breeding populations and 7746 progeny rows were evaluated for breeding purposes.

Practical Applications

We strive to provide Arkansas farmers with high-yielding locally adapted cultivars with low cost. The continued release of conventional and Roundup Ready public cultivars such as Ozark, UA 4805, Osage, UA 5612, UA 5213C, UA 5014C, UA 5414RR, and UA 5715GT provides low-cost seed for Arkansas growers and also serves as great sources of germplasm for breeding programs in the U.S.

Acknowledgements

The authors acknowledge the financial support of the Arkansas Soybean Promotion Board. We also thank the University of Arkansas System Division of Agriculture's Experiment Station personnel for the help and support with our field work. We also thank Arkansas Variety Testing Program for testing our lines prior to release.

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Table 1. Overview of University of Arkansas System Division of Agriculture's Soybean Breeding and Genetics Program tests in 2017.

Test	No. of entries
USDA Uniform/Preliminary Tests	35
AR Variety Testing Program	19
Arkansas advanced lines	345
Arkansas preliminary lines	1005
Progeny rows	7746
Breeding populations (F_1 – F_4)	1643
New crosses	137

Screening Soybean Germplasm and Breeding Soybeans for Flood Tolerance

L. Mozzoni[1], C. Wu[1], M. Orazaly[1], W. Hummer[1], L. Florez[1], and P. Chen[2]

Abstract

Flood, resulting from excessive rain, irrigation after rain, and fields with poor drainage, significantly reduces soybean yield. The University of Arkansas System Division of Agriculture's Soybean Breeding Program is committed to developing high-yielding flood-tolerant varieties for the southern soybean-producing regions. Advanced and preliminary breeding lines developed for the flood project were screened for response under flooded field conditions and they were also tested for yield potential under non-flooded conditions. Breeding populations were developed and advanced, and new crosses were made using flood tolerant sources and high-yielding cultivars and lines. In addition, advanced lines with exotic pedigree, drought-tolerant lines, lines with modified seed-composition traits, plant introductions from the United States Department of Agriculture (USDA) germplasm collection, and cultivars entered in the 2017 Arkansas Soybean Performance Test for maturity groups 4 and 5 were evaluated for flood response. Flood-tolerant sources were identified, and they will be used for breeding flood-tolerant lines in the future.

Introduction

Flooding is the second largest abiotic stress with significant economic impact to United States agriculture (Mittler, 2006; Bailey-Serres et al., 2012). National Aeronautics and Space Administration (NASA) weather simulation models predict that heavy precipitation events will increase by 30% by 2030 (Rosenzweig et al., 2002). Prolonged periods of rain, excessive irrigation, rainfall after irrigation, and impermeable soils are the causes of flooding. Soybeans grown under flooding conditions experience rhizosphere hypoxia (oxygen levels below optimal) and anoxia (complete lack of oxygen), both of which prevent plant growth. Flood damages include reduced plant-canopy height, dry-matter accumulation, and seed yield in soybean. Not many soybean cultivars are tolerant to flooding (Russell et al., 1990) and yield losses are estimated to be between 17% and 43% when flood stress occurs during the vegetative stage, and between 50% and 56% during the reproductive stage (Oosterhuis et al., 1990). Soybean plants tend to recover better if flooding occurs during vegetative growth stage compared to the reproductive growth stage (Scott et al., 1989). Sullivan et al. (2001) reported a 20% yield loss when soybean plots were flooded for three days at V2 and V3 growth stages. When plants flooded at the R5 stage, the yield reduction was between 20% and 39% in contrast to non-flooded checks (Rhine et al., 2010). Genetic variability for flood tolerance in soybean exists among different cultivars (VanToai et al., 1994). A three-year field study reported a 40% yield reduction in a soybean flood-tolerant group versus an 80% reduction in a flood-susceptible group (Shannon et al., 2005). It is our goal to improve flood tolerance in soybean and develop cultivars with competitive yield under flooded and non-flooded conditions. Flood screening of soybean cultivars that enter Arkansas Soybean Performance Test and identification of sources of flood tolerance have become ongoing goals of the University of Arkansas System Division of Agriculture's Soybean Breeding Program.

Procedures

The advanced lines were evaluated under flood conditions at the Rice Research and Extension Center near Stuttgart, Ark. with three replications to screen for flood response and also under non-flooded conditions to check yield potential in three Arkansas locations (Rice Research and Extension Center near Stuttgart, Pine Tree Research Station near Colt, and Northeast Research and Extension Center near Keiser) with three replications. To screen flood response, stress was imposed by flooding the field during the R1 to R2 stages and slowly draining after 5 days. The field was allowed to dry, and plots were allowed to recover for an additional 14 days before scoring for flood injury. Lines were scored using a 1 to 5 scale, where a score of 1 means no apparent injury and 5 means all plants are dead.

Preliminary lines developed for the flood project were evaluated for yield at two Arkansas locations (Rice Research and Extension Center near Stuttgart and Northeast Research and Extension Center near Keiser) and for flood tolerance at the Rice Research and Extension Center near Stuttgart. In addition, advanced lines in the soybean breeding program tested for flood stress included drought-tolerant lines, lines with exotic lines in the pedigree, lines with modified seed composition traits, Plant Introductions (PI) from germplasm collection, and cultivars entered in the 2017 Arkansas Soybean Performance Testing Program for maturity groups 4

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and 5. The breeding populations developed for the flood tolerance project were advanced using bulk pod descent method. New cross combinations were made using flood-tolerant sources and high-yielding cultivars and lines.

Results and Discussion

Out of eight advanced lines derived from flood-tolerant parents in the pedigree (Caviness × R08-2496, PI 471931 × PI 471938, R04-342 × 91210-350, R08-2416 × Jake, and RA-452 × R01-581F), three lines (R15-10832, R15-11648, and R15-7852) showed good tolerance to flood stress under flooding conditions (1.7–1.8 flooding scores) and they yielded 81–97% of mean yield of checks (AG4934 and AG 5335; 72.9 bu/ac) under non-flooded yield test (Table 1).

Out of 27 preliminary lines derived from flood-tolerant parents (Ozark × Jake, R07-6669 × Jake, R07-6669 × R09-2988, R07-6669 × UA 5612, R07-6669 × R10-412 RY, R08-47 × Jake, R08-1178 × Jake, R09-2567 × Jake, R09-430 × Jake, R09-230 × UA 5612, and TN08-100 × R11-262), seven lines (R16-1665, R16-45, 16-47, R16-72, R16-3416, R16-131, and R16-141) showed good tolerance to flood under flood screening test and yielded 91–102% of mean yield of checks (AG4632, AG4934, and AG5335; 82.1 bu/ac) under non-flooded yield test (Table 2). A total of 25 F_1, 22 F_2, 13 F_3, and 10 F_4 breeding populations derived from flood-tolerant and high-yielding parents were advanced.

Out of 133 commercial varieties (93 MG-4 and 40 MG-5) screened for flood tolerance, 11 cultivars (Delta Grow DG4835 RR2X, Delta Grow DG4940 RR, Delta Grow DG4995 RR, Dyna-Gro S45LL97, Dyna-Gro SX17852XT, Petrus Seed 4916 GT, Progeny P4255RX, Progeny P4444RXS, R15-7251, Pioneer P54A54X, and GO SOY 56C16) exhibited good flood tolerance with a flood score of 1.5 to 1.8. A total of 30 advanced lines with modified seed composition traits developed in our breeding program were tested for flood tolerance and 2 of them, R13-14007 and R14-2090, showed good tolerance to flood with flood score of 1.8 and 1.7, respectively. Out of 23 drought-tolerant lines screened for flood stress, 2 lines, R11-2836, and R15-7651, exhibited tolerance to flooding with 1.5 and 1.8 flood score, respectively. Out of 27 lines with exotic germplasm in the pedigree, 8 lines (R11-6870, R14-12881, R15-7230, R15-7245, R15-7251, R15-7092, R15-7025, and R15-6950) showed flood tolerance with a score of 1.3 to 1.8. Out of 433 PIs from the USDA germplasm collection, 51 PIs were identified as flood tolerant with a flood score of 1.2 to 1.8

Practical Applications

The University of Arkansas System Division of Agriculture's Soybean Breeding Program continuously improves flood screening methodologies and it allows the identification of new sources of flood tolerance from diverse germplasm. Once this trait is incorporated into high-yielding background, it will be possible to offer the growers waterlogging-tolerant varieties that will maintain their yield under flood stress.

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Table 1. Flood screening and yield evaluation of advanced lines in 2017.

Name	Pedigree	Yield[a] (bu/ac)	% Check Mean[b] (%)	Flood score[c] (1 to 5)
AG4934	N/A	72.9	100	4.3
AG5335	N/A	72.9	100	2.8
R15-11710	RA-452 × R01-581F	72.7	100	2.7
R15-10957	R04-342 × 91210-350	70.9	97	3
R15-10832	R04-342 × 91210-350	70.6	97	1.8
R15-7852	Caviness × R08-2496	67.4	92	1.7
R15-11802	RA-452 × R01-581F	61.4	84	3.5
R15-11648	PI 471931× PI 471938	59.4	81	1.8
R15-7794	R08-2416 × Jake	59	81	2.8
R15-7817	R08-2416 × Jake	58.6	80	3

[a]combined yield across three locations.
[b]comparison to check mean.
[c]1 = no flood injury and 5 = all plants dead.

Table 2. Flood screening and yield evaluation of preliminary lines in 2017.

Name	Pedigree	Yield[a] (bu/ac)	% Check mean[b] (%)	Flood score[c] (1 to 5)
AG4934	N/A	90.1	110	3.8
R16-47	R07-6669 × UA5612	83.6	102	1.8
R16-1272	Ozark × Jake	81.1	99	2.5
R16-141	R10-230 × UA5612	79.2	96	1.5
R16-72	R07-6669 × UA5612	78.5	96	1.7
AG4632	N/A	78.3	95	2.8
R16-3416	R07-6669 × R10-412 RY	78.2	95	1.7
R16-1729	R07-6669 × R09-2988	77.8	95	2.5
AG5335	N/A	77.8	95	3.3
R16-131	R10-230 × UA5612	77.5	94	1.7
R16-1700	R07-6669 × R09-2988	75.9	92	2.5
R16-1676	R07-6669 × R09-2988	75.6	92	2.5
R16-378	TN08-100 × R11-262	75.5	92	2.2
R16-45	R07-6669 × UA5612	75.3	92	1.7
R16-1665	R07-6669 × Jake	74.7	91	1.8
R16-1781	R08-1178 × Jake	74.3	91	2.3
R16-1858	R08-47 × Jake	73.9	90	2.7
R16-3425	R07-6669 × R10-412 RY	73.2	89	2.7
R16-1855	R08-47 × Jake	73.1	89	3.7
R16-2152	R09-430 × Jake	72.8	89	2.2
R16-136	R10-230 × UA5612	72.8	89	2
R16-2137	R09-430 × Jake	72.7	89	2.2
R16-3426	R07-6669 × R10-412 RY	72.5	88	2.7
R16-1706	R07-6669 × R09-2988	71.8	88	1.7
R16-1684	R07-6669 × R09-2988	71.4	87	2.8
R16-2012	R09-2567 × Jake	70.7	86	2.3
R16-2158	R09-430 × Jake	69.8	85	3.7
R16-1864	R08-47 × Jake	69.3	84	3
R16-2149	R09-430 × Jake	66.6	81	3
R16-2139	R09-430 × Jake	66.1	81	3

[a]combined yield across three locations.
[b]comparison to check mean.
[c]1 = no flood injury and 5 = all plants dead.

Purification and Production of Breeder Seed and Foundation Seed of University of Arkansas Soybean Lines

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Abstract

The main goal of the University of Arkansas System Division of Agriculture's Soybean Breeding and Genetics program is to develop high-yielding varieties and provide pure breeder seed for commercialization. We continuously work on improving yield, quality, drought, flooding and disease resistance, as well as salt tolerance to southern soybean producers. And we produce breeder seed for our potential releases and maintained purity of future releases to seed dealers and farmers. This report summarizes the purification and pre-foundation efforts during the 2017 growing season.

Introduction

The main objective of the University of Arkansas System Division of Agriculture's Soybean Breeding and Genetics Program is to develop high-yielding locally adapted soybean cultivars. The demand for conventional varieties has solidified the need for public breeding programs since private companies have focused primarily on genetically modified varieties. Also, generic glyphosate-tolerant varieties provide a lower seed cost alternative to farmers, who can then save the seed for planting the following year. Since the patent for Roundup-Ready® technology expired in 2015, 2 glyphosate-tolerant cultivars were released. Specialty traits were incorporated into our breeding program by developing high-yielding varieties with increased protein, oil, sugar, or modified fatty acids. These traits provide the farmers an opportunity for a supplemental profit on their crop.

Procedures

The Soybean Breeding and Genetics Program grows breeder seed and plant row purifications and rogue for off-types or mixtures. In 2017, foundation seed were produced for: 31 acres of Osage, 50 acres of UA 5612, 70 acres of UA 5213C, 24 acres of UA 5014C, 160 acres of UA 5414RR, and 50 acres of UA 5715GT. Out of the total 385 acres, 155 acres were planted at the Rice Research and Extension Center near Stuttgart and 230 acres were planted in Pine Tree Research Station near Colt (Table 1).

Every five years our released cultivars are purified to provide a new clean source for foundation seed. Three hundred single plants are pulled and seed of each plant is grown in a row to check flower color and leaf shape during blooming and pubescence color, pod wall color, plant height, and maturity during maturity. Each row is harvested individually, and seed is checked for seed size and hilum color. Rows with off-types are discarded.

Foundation, pre-foundation, and breeder seed lots were rogued for off-types throughout the growing season and checked for seed traits in the lab. Each line is tested for target traits such as protein, oil, sugar, or fatty acid content. They were also submitted for disease testing: root-knot nematode, reniform nematode, soybean cyst nematode, stem canker, sudden death syndrome, and frogeye leaf spot, as well as for salt tolerance.

Results and Discussion

In 2017, a total of 6282 units of conventional and round-up ready soybeans were sold including 866 units of Osage, 601 units of UA 5612, 610 units of UA 5213C, 2335 units of UA 5414RR, 778 units of UA 5014C, and 1092 units of UA 5715GT. In addition, a total of 2702 advanced orders were placed for 2018 including 375 units of Osage, 385 units of UA 5612, 175 units of UA 5213C, 1014 units of UA 5414RR, 350 units of UA 5014C, and 403 units of UA 5715GT (Table 2).

In 2017, two high-yielding conventional cultivars were licensed, UA 5115C (formerly R09-430) and UA 5615C (formerly R10-230) were purified. Two of our released cultivars, R10-230 and R08-4004, were purified. Three hundred individual plants from each cultivar were pulled in 2016 and each plant was planted in a single row in 2017. Each row was extensively rogued during blooming and maturity. Each row was harvested individually and checked for the hilum color and seed size.

Potential releases underwent a pre-foundation seed increase in 2017. A total of 0.25 acres for each of pre-foundation seed were produced for: five MG 4 lines (R13-1019, R12-712, R12-226, R13-13433, and R11-328), one high oleic and low linolenic line (UARK-288), and two large-seeded lines (R14-6450, and R07-589).

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Practical Applications

Production of breeder and foundation seed of different varieties such as conventional, glyphosate-tolerant, and with modified-seed composition developed at the Soybean Breeding and Genetics program of the University of Arkansas System Division of Agriculture provides high quality seed with good germination to local soybean producers, enhancing the competitiveness of Arkansas soybean in both the national and international markets.

Table 1. 2017 Foundation and pre-foundation seed overview.

Test	Name	Project	Acres planted	Location[a]	Purification rows produced
Foundation	Osage	Conventional	31	RREC	2017 RREC
Foundation	UA 5612	Conventional	50	PTRS	2015 PTRS
Foundation	UA 5213C	Conventional	70	PTRS	2017 RREC
Foundation	UA 5014C	Conventional	24	RREC	2017 RREC
Foundation	UA 5414RR	Roundup ready	160	RREC100/PTRS 60	2015 PTRS
Foundation	UA 5715GT	Roundup ready	50	PTRS	2015 RREC
Pre-foundation	R13-1019	Conv (MG4)	0.25	RREC	
Pre-foundation	R12-712	Conv (MG4)	0.25	RREC	
Pre-foundation	R12-226	Conv (MG4)	0.25	RREC	
Pre-foundation	R13-13433	Conv (MG4)	0.25	RREC	
Pre-foundation	R11-328	Conv (MG4)	0.25	RREC	
Pre-foundation	UARK-288	HOLL	1.0	RREC	
Pre-foundation	R14-6450	VEG	0.18	RREC	
Pre-foundation	R07-589	VEG	0.18	RREC	

[a]RREC – Rice Research and Extension Center near Stuttgart, and PTRS-Pine Tree Research Station near Colt

Table 2. 2017 Foundation seed sales and advanced orders.

Variety name	Sales in 2017 (50 lb units)	Advanced orders for 2018 (50 lb units)
Osage	866	375
UA 5612	601	385
UA 5213C	610	175
UA 5414RR	2335	1014
UA 5014C	778	350
UA 5715GT	1092	403

Soybean Germplasm Enhancement Using Genetic Diversity

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Abstract

Introducing germplasm with enhanced yield, disease resistance, stress tolerance, and seed composition traits is one of the objectives of the Soybean Breeding and Genetics Program of the University of Arkansas System Division of Agriculture. In 2017, two maturity group (MG) 5 germplasm were released, R10-5086 and R11-6870, with 25% exotic Plant Introductions (PI) in the pedigree and 99% and 96% of check yield (Osage, 65.6 bu/ac), respectively. Two drought-tolerant germplasm (R10-2436 and R10-2710) with high yield under irrigation and low yield reduction under drought were also released. Germplasm lines R10-2436 and R10-2710 yielded 74.7 and 71.4 bu/ac under irrigation (2012 to 2016 data), respectively, compared to mean yield of MG 5 commercial checks. Under drought, R10-2436 and R10-2710 exhibited 26% and 28% yield reduction, respectively, compared to 44% average yield reduction in MG 5 commercial checks. All four germplasm lines are available for public and private breeders to be used as parents to develop lines with enhanced stability under drought.

Introduction

Continuous introduction of new germplasm using Plant Introductions (PI) and lines with exotic pedigree from other breeding programs is the main aspect of the germplasm enhancement project. By introducing exotic lines, new yield, disease resistance, stress tolerance, and/or seed composition genes are discovered that can be utilized in the breeding program. The soybean genetic base used in breeding for cultivar development in the United States is narrow, and 26 ancestors account for 90% of the total ancestry of cultivars used from 1947 to 1988 (Gizlice et al., 1994). An exotic germplasm must have a yield comparable with the locally adapted cultivars/lines to be used in breeding. Thus, more than one breeding cycle may be necessary to improve the agronomic performance of the introduced germplasm before it can be crossed with the local parents.

Five soybean germplasm with genetic diversity in the pedigree have been released from the University of Arkansas System Division of Agriculture's Soybean Breeding and Genetic's Program as a result of using exotic lines in the breeding effort: R99-1613F, R01-2731F, R01-3474F (Chen et al., 2011), R10-5086, and R11-6870 (Chen et al., 2007). The Soybean Breeding Program uses exotic germplasm to increase not only genetic diversity for yield improvement but also for pest resistance, stress tolerance, and modified-seed composition traits including high protein, high oil, high oleic, low linolenic, high sucrose, low stachyose, and low phytate.

Procedures

A total of 80 crosses were made in 2017 for germplasm enhancement. The F_1 breeding populations were grown and were checked for the presence of morphological markers.

The breeding populations were advanced using the modified single-pod descent method (Fehr, 1987) from F_2 to F_4 generations. Single plants were selected in F_3-F_4 breeding populations and individually harvested to generate pure lines. The advanced and preliminary lines with the best agronomic performance were extensively evaluated in Arkansas and other southern states for yield, maturity, lodging and shattering tolerance, and target traits according to the breeding objective.

Results and Discussion

Genetic Diversity for Yield Improvement. In 2017, 2 high-yielding maturity group (MG) 5 germplasm lines were released (R10-5086 and R11-6870) with 25% of exotic germplasm in the pedigree (25% PI 290126B and 25% PI 594208, respectively). Yields of R10-5086 and R11-6870 are 99% and 96% of the check (Osage 65.6 bu/ac), respectively. The importance of these releases lies in the need to introduce new alleles to the narrow soybean genetic basis used for cultivar development in the United States. Both R10-5089 and R11-6878 are available to public and private breeders.

In 2017, as part of the effort to develop new high-yielding lines with diverse germplasm in the pedigree, 27 advanced and 27 preliminary lines originated from breeding populations carrying 25% to 50% of exotic pedigree were evaluated (Table 1). Advanced lines were evaluated in three Arkansas locations with three replications. Lines yielded between 42.3 and 84 bu/ac compared to the check mean yield of 76.9 bu/ac (AG4934, AG5335, and P5555). Ten lines yielded ≥95% of the average check yield. An advanced line R15-7063 significantly out-yielded (84 bu/ac) the highest yielding check, AG4934 by 4.1 bu/ac showing potential for multi-state trial testing in 2018.

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Preliminary lines were tested in two Arkansas locations. Two of them, R16-378 and R16-3811, yielded 82.4 bu/ac and 90.1 bu/ac compared to the check mean yield of 85.1 bu/ac (AG4934, AG4632, and P5555). These high-yielding lines will be further evaluated in 2018.

In addition, 50 F_4, 33 F_3, 50 F_2, and 19 F_1 breeding populations derived from parents carrying 25% to 50% of exotic germplasm in the pedigree were advanced to subsequent breeding stages.

Drought Tolerance. In 2017, two drought-tolerant germplasm lines were released (R10-2436 and R10-2710) with high yield under irrigation and low yield reduction under drought. Lines R10-2436 and R10-2710 yielded 74.7 and 71.4 bu/ac under irrigation (2012 to 2016 data), respectively, compared to the MG 5 check mean yield of 73.6 bu/ac. Under drought, R10-2436 and R10-2710 exhibited 26% and 28% yield reduction, respectively, compared to 44% average yield reduction in MG 5 commercial checks. The yield advantage of these germplasm under drought conditions could be contributed to their potential to fix nitrogen at lower soil-water content. Line R10-2436 also carries the slow-wilting trait inherited from PI 416937. Both germplasm lines are available for public and private breeders to be used as parents to develop drought-resistant lines.

In 2017, 23 advanced and 12 preliminary lines derived from crosses among drought-tolerant lines from Arkansas and other states were evaluated (Table 1). Advanced lines were tested in three Arkansas locations with three replications and yielded between 56.3 and 70.2 bu/ac compared to the 65.6 bu/ac yield of checks (AG5335 and P5555) under irrigated conditions. Three best lines in the test, R13-12468, R11-2735, and R13-11677, yielded 65.6 to 70.2 bu/ac. Under drought, these three lines had 27–35% yield reduction compared to the checks that had 33% yield reduction. Preliminary lines yielded between 64.1 and 81.3 bu/ac. Two lines, R16-4053 and R16-3989, yielded 81.2 bu/ac and 81.3 bu/ac, respectively, compared to the check mean yield of 79.6 bu/ac. These preliminary lines will be evaluated under irrigated and drought conditions in 2018. Populations advanced for the drought project were 34 F_4, 18 F_3, 32 F_2, and 13 F_1.

Pest and Disease Resistance. The Soybean Breeding and Genetics Program breeds to develop varieties with resistance to sudden death syndrome (SDS), frogeye leaf spot (FLS), phomopsis seed decay (PSD), soybean cyst nematode (SCN), Asian soybean rust (ASR), and stink bugs (SB), as well as salt stress. In 2017, a total of 23 advanced and 61 preliminary lines, originated from crosses for disease and pest resistance were evaluated (Table 1). Six advanced lines yielded ≥95% of check mean yield (78.9 bu/ac). Lines R11-982G and R11-1294 both yielded 78.4 bu/ac compared to the check mean yield of 78.9 bu/ac. In addition, 29 F_4, 7 F_3, 29 F_2, and 11 F_1 breeding populations for the pest and disease resistance project were advanced. Pest and disease resistance is confirmed on advanced breeding lines, only after lines are selected over multiple years for yield and local adaptation.

Seed Composition Traits. We introduce novel sources of germplasm to develop lines with modified seed composition traits such as high protein, high sucrose with low stachyose/phytate, and high oleic with low linolenic fatty acids. For the high protein project, during 2017 we made eight new cross combinations between plant introductions (PIs) from the Germplasm Bank containing high protein (42.7% to 43.6% protein) and regular oil content (20.8% to 22.3% on dry-weight basis) with our high-yielding varieties/lines. These MG 4 and MG 5 PIs will provide new sources of high protein in addition to commonly used 'BARC-7' allele. In addition, in 2017 we advanced 25 F_4, 23 F_3, 12 F_2, and 19 F_1 high-protein populations. Due to the demand for high-oleic soybean varieties, we have developed lines with high oleic and/or low linolenic fatty acid content. Our most advanced lines are UARK-479, UARK-288, and UARK-488 which have 84.0–85.0% oleic, 2.8–3.5% linolenic fatty acid, and 89–91% check yield.

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Table 1. Germplasm enhancement project overview in 2017.

Test	# of Advanced test entries	# of Preliminary test entries
Genetic diversity	27	27
Drought tolerance	23	12
Pest and disease resistance	23	61
Modified fatty acid	55	255

Accelerated Development of Bioherbicides to Control Palmer Amaranth

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Abstract

Palmer amaranth (pigweed) is a problematic and expensive management issue for Arkansas soybean producers. In addition to growing rapidly and prolifically producing seed, pigweed in Arkansas has developed herbicide resistance, which has contributed to increasing chemical management practices and associated costs over the last decade. Bioherbicides derived from fungal pathogens that naturally infect weeds are promising as alternative measures to control herbicide-resistant pigweed populations. Our overarching goal in this study is to create novel, highly aggressive bioherbicide products through unique molecular genetic approaches that specifically and effectively suppress Arkansas populations of pigweed. To date, pigweed-associated fungi and pigweed seed have been collected throughout Arkansas to identify candidate organisms for bioherbicide development. A total of 109 fungal isolates were collected from diseased pigweed. Of these, 86 isolates were collected from foliar material and 23 isolates were collected from seeds and diseased stalk material. Morphological and/or molecular identification revealed species of *Colletotrichum, Cercospora, Fusarium*, and *Leptosphaeria* in the collection, which provides excellent candidate organisms to enhance virulence via gene-editing approaches. The collection is currently being evaluated in pigweed pathogenicity assays to identify highly aggressive isolates for use as bioherbicides.

Introduction

Palmer amaranth (*Amaranthus palmeri*), commonly referred to as pigweed, is the most problematic weed for Arkansas soybean production. Rapid growth, abundant seed production, and germination throughout the season (Horak and Loughin, 2000; Sellers et al., 2003) make pigweed a challenge for soybean growers throughout the state. The presence of pigweed in soybean fields can reduce yields substantially (Bensch et al., 2003).

The use of glyphosate in conjunction with glyphosate-tolerant soybean cultivars historically provided effective control of pigweed. In 2013, more than 98% of soybean and cotton planted in Arkansas were glyphosate-tolerant (Scott and Smith, 2013). This control measure was notably different from previous weed control approaches, allowing post-emergence application of a broad-spectrum herbicide to control most weeds (Green and Owen, 2011). Even though highly effective, continuous application of glyphosate eventually led to the emergence of glyphosate resistance in pigweed (Green and Owen, 2011). In addition to pigweed, 23 weed species in Arkansas have shown resistance to glyphosate and other herbicides with diverse modes of action (Heap, 2018). As such, managing pigweed, particularly herbicide-resistant pigweed, has helped drive an estimated 75% increase in total chemical expenditures over the last decade (Butts et al., 2016). Therefore, the identification and implementation of sustainable and cost-effective strategies to control pigweed are critical for Arkansas soybean production.

Biological control refers to the introduction of organisms into an ecosystem to control undesirable species (Charudattan, 2001). In this context, fungi, bacteria, and to some extent, viruses have been explored as bioherbicides against weedy and invasive plant species in the last decade (Li et al., 2003; Elliott et al., 2009; Diaz et al., 2014). Bioherbicides, also known as inundative biological control, comprise bacterial suspensions or fungal spores of virulent strains in concentrations far above those normally found in nature, which suppress weed/invasive species upon application (Johnson et al., 1996; TeBeest, 1996). Bioherbicides have considerable promise in agricultural systems, as they can be applied in granular formations or liquid sprays, similar to conventional herbicides (Harding and Raizada, 2015; Auld et al., 2003; Caldwell et al., 2012). Additional benefits of bioherbicides include lower production costs compared to other chemical agents (Auld and Morin, 1995; Li et al., 2003), lower environmental impact (Li et al., 2003), and higher public acceptance (Anderson et al., 1996; Bazoche et al., 2014).

Many commercial biological weed control products developed in North America are derived from fungal pathogens. Collego (*Colletotrichium gloeosporioides* f. sp. *aeschynomene*) and BioMal (*C. gloesporioides* f. sp. *malvae*) are examples of bioherbicides to control northern jointvetch (*Aeschynomene virginica*) and round-leaved mallow (*Malva pusilla*), respectively (Mortensen, 1988; Daniel et al., 1973). In addition, a *Sclerotinia minor*-based formulation called Sarritor was introduced to control dandelion (*Taraxacum officinale*), white clover (*Trifolium repens*), and broadleaf plantain (*Plantago*

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major) in turf (PMRA, 2010). However, bioherbicides have yet to be developed for pigweed. Thus, the goal of this project is to create novel, highly aggressive bioherbicide products through unique molecular genetic approaches that specifically and effectively suppress Arkansas populations of pigweed. A diverse collection of pigweed-associated fungi and pigweed seed from throughout the state has been established and is currently being evaluated in pigweed pathogenicity assays to identify highly aggressive isolates for potential use as bioherbicides.

Procedures

To establish a collection of foliar, stalk-rot, and seed-borne pigweed pathogens, diseased pigweed was scouted and sampled extensively throughout eastern and northwest Arkansas in 2017 (Fig. 1). Additional seeds and diseased stalk tissue of pigweed were previously collected in fall of 2016. Diseased material was collected from soybean and long-term weed plots on University of Arkansas System Division of Agriculture's Cooperative Extension Service research stations throughout the state, as well as from growers' fields and ditch banks.

Diseased material was surface disinfested for 1 min in 0.6% hypochlorite, followed by 1 min in 70% ethanol, and finally rinsed in sterile water. Following surface disinfestation, diseased material was placed on 2% water agar (Hardy Diagnostics, Springboro, Ohio) amended with 75 µg/ml carbenicillin (Research Products International, Mt. Prospect, Ill.) or placed in moist chambers and incubated at 23 °C in the dark. Fungal isolates were transferred to V8 agar (Leslie and Summerell, 2006) amended with 75 µg/ml carbenicillin and incubated at 23 °C in the dark. For long-term maintenance, fungal isolates were stored as mycelia in 30% (v/v) glycerol at −80 °C.

Seed used in greenhouse assays should ideally represent the high level of genetic diversity present in Arkansas pigweed populations. Thus, seeds were collected from multiple plants in various locations across the state. Seeds were blended into seed lots, so that greenhouse evaluations of virulence are performed against mini-populations of pigweed representing the natural diversity present in Arkansas.

Results and Discussion

In spring and early summer of 2017, natural levels of disease were higher than in previous years, likely due to more frequent rainfall and high levels of humidity. Foliar disease pressure was particularly high (Fig. 2A-C). A total of 86 fungal isolates were collected from symptomatic foliar material. The most common and aggressive foliar disease encountered on pigweed was a leaf spot disease, consistent with those caused by fungi belonging to the Dothideomycetes class (Fig. 2A). This disease was observed and collected from nearly every county sampled, as indicated in Fig. 1. Because of its severity and prevalence across Arkansas, this pathogen appears to be virulent on genetically diverse populations of pigweed, and thus it will be an excellent candidate for development as a bioherbicide. Diseased stalk tissue of pigweed was also observed (Fig. 2D-F), and a total of 23 fungal isolates were collected from seeds and diseased stalk tissue. Collection of additional isolates from seeds and stalk material is underway.

Morphological identification indicated the majority of isolates collected from pigweed, regardless of tissue type, belonged to the genus *Colletotrichum* (Fig. 3A-B). A relatively high number of *Cercospora* and *Fusarium* isolates were collected from foliar tissue and stalk tissue, respectively (Fig. 3A-B). Molecular identification is underway to further resolve the taxonomic identity of each isolate. Initial results from molecular identification of seed and stalk isolates identified species of *Colletotrichum* and *Leptosphaeria*, both of which have promise as biocontrol organisms. Ultimately, one approach would be to use gene editing to optimize virulence in pathogens with different infection strategies and combine these into a commercial product that simultaneously targets pigweed juveniles and the quality of seed production by adult plants.

Practical Applications

Herbicide-resistant Palmer amaranth (pigweed) is one of the most troubling and expensive management issues for Arkansas soybean producers. The use of bioherbicides based on fungal pathogens that naturally infect (cause disease on) weed species is a promising strategy to effectively and sustainably control herbicide-resistant pigweed. Development of a novel bioherbicide product that specifically and effectively suppresses Arkansas populations of pigweed will increase the profitability of soybean production in Arkansas by decreasing chemical expenditures. Additionally, a more environmentally friendly option to control pigweed populations in Arkansas will be available to soybean producers, which will support more sustainable weed management practices.

Acknowledgements

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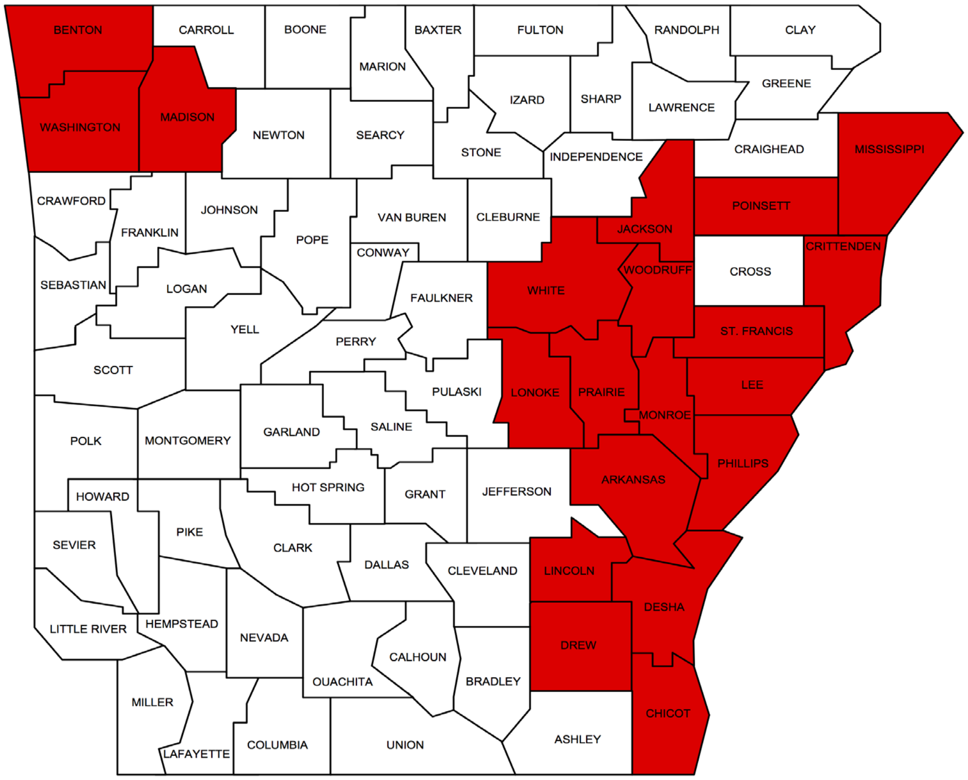

Fig. 1. Locations, in red, of scouting and sampling for Palmer amaranth diseases. (Spring and Summer 2017).

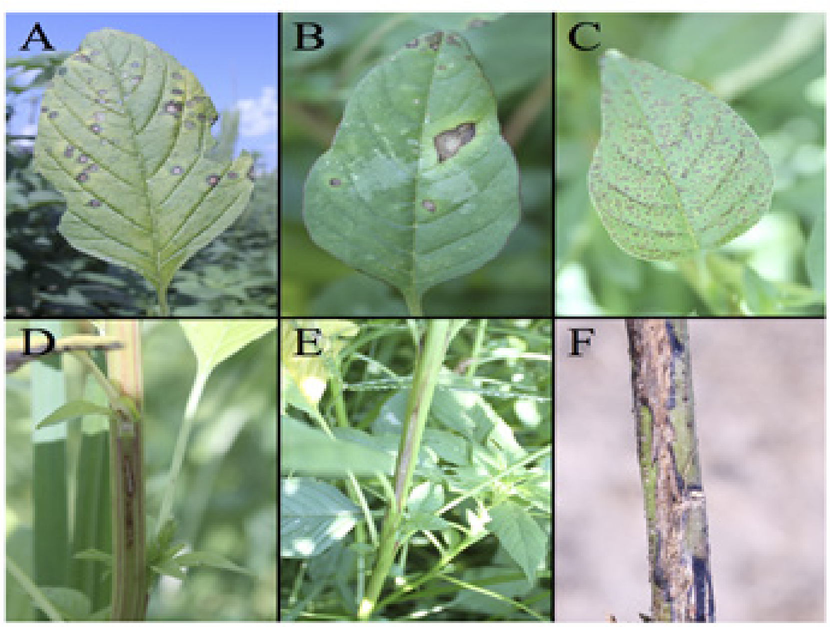

Fig. 2. Representative foliar (A, B, and C) and stalk lesions (D, E, and F) found on Palmer amaranth.

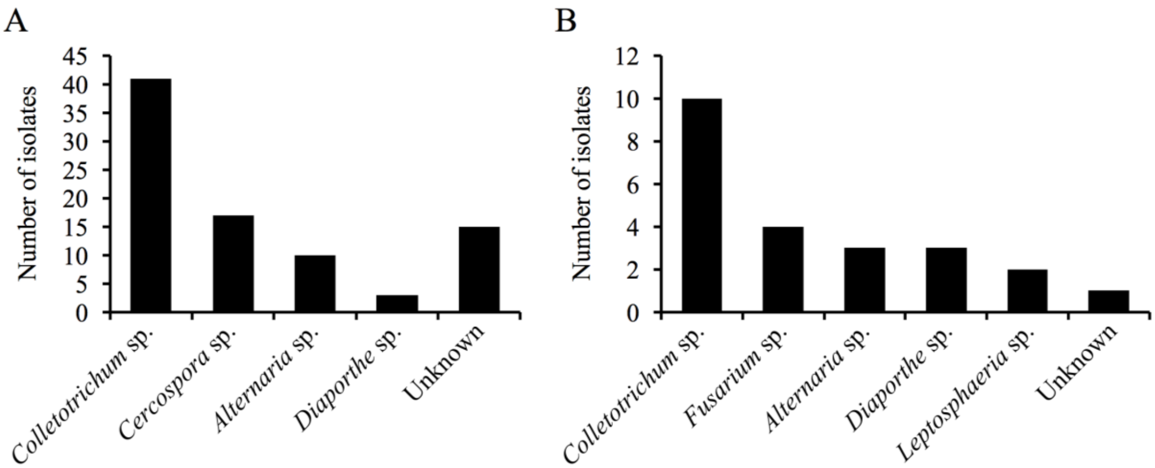

Fig. 3. Number of morphologically characterized fungal isolates collected from foliar tissue (A) or seeds and stalk tisssue (B) of Palmer amaranth.

Evaluation of Automatic Applications on Profitability of Soybean Production

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Abstract

Automatic applications of insecticides and fungicides have become commonplace for many growers and consultants and the economic benefit of these applications is not clear. Studies were conducted throughout the 2015 to 2017 growing seasons on grower soybean fields throughout the state comparing yields of threshold treated plots and plots receiving automatic chlorantraniliprole and/or fungicide treatments. Results indicate that automatic applications did enhance soybean yield but on average did not provide an economic benefit to the grower.

Introduction

Chlorantraniliprole is an anthranilic diamide class insecticide and exhibits a great amount of activity on lepidopteran pests of soybean. Chlorantraniliprole moves systemically throughout the plant and provides exceptionally long residual control when compared to many other insecticides (Hardke et al., 2015, Adams et al., 2016). Because of this, many growers and consultants make automatic applications of insecticide along with a fungicide at the R3 growth stage, allowing them to spend minimal amounts of time scouting the field for insects in the following weeks. There have also been claims that chlorantraniliprole applications can increase soybean yields even in fields with subthreshold insect densites. These studies evaluate the profitability of automatic insecticide and fungicide applications in soybean versus treating only as needed based on University of Arkansas System Division of Agriculture's thresholds.

Procedures

Experiments were conducted throughout Arkansas to evaluate the automatic applications of insecticides in soybean from 2015 through 2017. Multiple grower fields were used in the Northeast, Central, and Southeast portions of the state. Four automatic applications were compared to a treat-only-as-needed treatment. Automatic applications of Prevathon, a fungicide, and the combination of Prevathon and fungicide were made at the R3 growth stage. At the R5 growth stage another application of fungicide was applied to some of the plots receiving the initial Prevathon plus fungicide application. The treat-when-needed was only treated when insect pests reached action threshold. Plots were sampled weekly following the initial R3 automatic applications. All applications were made with a high clearance sprayer at 10 gallons per acre. Yield was taken using the growers combine and yield monitor.

Results and Discussion

In 2015, automatic applications increased yield at Griffin and Fortner locations compared to the untreated check while the Crowe location appeared to benefit from any treatment containing a fungicide (Table 1). No yield advantages were observed for the other 3 locations. In 2016, similar trends were observed to the previous year with Griffin and Fortner locations receiving a benefit to the automatic applications (Table 2). The Farr and Crowe location appeared to benefit from the treatments with a fungicide and the Miles location had a yield increase only for the fungicide + insecticide treatment. In 2017, all treatments significantly increased yields at the Gerard and Wilson locations and the highest yield was with the insecticide + fungicide followed by a second application at both the Gerard and Higginbotham locations (Table 3).

In 2015 and 2017 all treatments increased yield over the untreated check, and in 2016 all treatments except the insecticide treatment increased yields (Table 4). This would indicate that one or two applications of fungicide did increase yields in most cases and in a majority of locations. The factors for the increase in yield are largely unknown but would indicate we have much to learn about the use of fungicides and their impact on soybean. Insecticide increased yield over the untreated 24% of the time compared to the fungicide alone at 41% of the time, fungicide + insecticide at 38% of the time and the fungicide + insecticide plus another fungicide application at 64% of the time. The fungicide + insecticide plus a second application of fungicide increased

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yields on average 7.7 bu/ac. However, the average increase for all treatments was insufficient to cover the costs of the pesticide plus the application. There were instances where we observed increased yields that would more than pay for the cost of pesticide and application. This may be due to the cultivar used and indicates the importance of cultivar selection particularly in areas of high disease incidence.

Practical Applications

This research found that automatic applications of insecticides and fungicides did commonly increase yields in Arkansas soybean but the average increases in yield were not sufficient to pay for the cost of the pesticide and application. Data produced from this research will help growers increase profitability by reducing unnecessary pesticide applications.

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Table 1. Yields of plots by location receiving automatic and threshold pesticide applications in 2015.

Treatment	Farr† Armor 55R22	Griffin‡ Asgrow 4232	Fortner§ Asgrow 4632	Crowe¶ Asgrow 4642	Miles Pioneer 47T36	Lost Cane Asgrow 4710
	bu/ac					
Prevathon 14 oz + fungicide at R3	76.03 a	48.08 b	67.18 a	73.98 a	77.76 a	85.8 a
Prevathon 14 oz at R3	74.87 a	48.86 b	60.35 b	63.74 b	74.52 a	88.1 a
Fungicide only at R3	75.16 a	48.06 b	59.96 b	72.65 a	68.57 a	84.1 a
Threshold	76.71 a	41.44 c	54.72 c	63.12 b	73.55 a	84.2 a
Prevathon 14 oz + Fungicide at R3 Fungicide only at R5		54.09 a		75.18 a	66.82 a	

† Approach Prima 6.8 oz.
‡ Topaz 6 oz + Priaxor 4 oz fb Priaxor 4 oz.
§ Topaz 6 oz + Priaxor 4 oz.
¶ Priaxor 4 oz at R3 & R5.

Table 2. Yields of plots by location receiving automatic and threshold pesticide applications in 2016.

Treatment	Farr†	Griffin†	Fortner†	Keiser ‡	Crowe‡	Miles‡
	bu/ac					
Prevathon 14 oz + Fungicide at R3	69.03 a	67.61 b	69.83 b	48.91 a	52.73 ab	78.58 a
Prevathon 14 oz at R3	63.73 b	67.23 b	68.29 bc	47.68 a	52.70 ab	74.95 b
Fungicide only at R3	68.28 a	68.48 b	71.30 b	49.44 a	52.98 a	72.85 b
Threshold	64.61 b	65.53 c	65.86 c	45.5 a	52.30 b	72.33 b
Prevathon 14 oz + Fungicide at R3 Fungicide only at R5	68.91 a	73.40 a	75.91 a	46.39 a	53.00 a	73.33 b

† Topaz 6 oz + Priaxor 4 oz; fb Priaxor.
‡ Priaxor 4 oz at R3 & R5.

Table 3. Yields of plots by location receiving automatic and threshold pesticide applications in 2017

Treatment	Gerard†	Higginbotham† 48D24	Metheney‡	Wilson‡	Miles‡ P47T36
	--------	--------	bu/ac	--------	--------
Prevathon 14 oz + Fungicide at R3	65.78 ab	53.02 b	71.68 b	51.38 a	82.03 ab
Prevathon 14 oz at R3	64.56 b	50.19 b	66.05 c	48.73 a	79.71 b
Fungicide only at R3	67.03 a	47.23 b	70.53 b	50.55 a	84.81 a
Threshold	61.17 c	48.48 b	73.85 a	44.20 b	82.66 ab
Prevathon 14 oz + Fungicide at R3 Fungicide only at R5	65.50 b	60.20 a	64.85 c	49.60 a	85.78 a

† Topaz 6 oz + Priaxor 4 oz; fb Priaxor.
‡ Priaxor 4 oz at R3 & R5.

Table 4. Yields of plots across sites by year and across site years receiving automatic and threshold pesticide applications in 2015-2017

Treatment	2015	2016	2017	2015-2017
	--------	-------- bu/ac	--------	--------
Prevathon 14 oz + Fungicide at R3	75.13 a	65.05 b	64.3 a	68.36 a
Prevathon 14 oz at R3	71.22 a	63.26 bc	62.34 ab	65.51 b
Fungicide only at R3	71.42 a	64.51 b	63.19 ab	66.32 ab
Threshold	65.01 b	61.81 c	62.88 c	63.01 c
Prevathon 14 oz + Fungicide at R3 Fungicide only at R5	72.69 a	68.56 a	59.64 b	67.25 ab

Efficacy of *Chrysodeixis includens* Nucleopolyhedrovirus for Control of Soybean Looper

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Abstract

An experiment was conducted to evaluate the efficacy of *Chrysodeixis includens* nucleopolyhedrovirus (ChinNPV) on soybean looper. Prevathon® provided greater control of soybean looper at 3 and 7 days after treatment than ChinNPV. At 10 days after treatment, Prevathon still provided the greatest control of soybean looper but two of the tested rates of ChinNPV were no different than Prevathon. ChinNPV could provide an effective control option for soybean looper; however more research needs to be conducted in order to ensure this product's effectiveness.

Introduction

Soybean looper (SBL), *Chrysodeixis includens* (Walker), is a perennial pest of soybean in Arkansas. This pest migrates from the south, resulting in it being a larger problem on later planted soybean. In 2016, SBL resulted in over $15 million in losses plus cost to Arkansas growers (Musser et al., 2017). Soybean looper has become increasingly difficult to control due to resistance to multiple classes of insecticides (Boethel et al., 1992). Currently a nucleopolyhedrovirus is being commercialized for SBL and will give farmers another control option for this pest.

Procedures

A trial was conducted on a grower field in Phillips County, Arkansas to evaluate the efficacy of *Chrysodeixis includens* nucleopolyhedrovirus (ChinNPV) on soybean looper (SBL). The soybean cultivar used was Asgrow 4632. Plot size was 4 rows by 50 feet long on 38-inch rows, arranged in a randomized complete block design with 4 replications. Insecticides were applied with a Mud-Master sprayer equipped with a multi-boom delivering 10 gpa at 40 psi through 80-02 dual flat fan nozzles with 19.5-inch spacing. Insecticide application occurred on 30 August. Soybean looper densities were determined by taking 25 sweeps per plot with a 15-in diameter net. Samples were taken on 2 Sept., 6 Sept., and 9 Sept., 3, 7, and 10 days after treatment (3 DAT, 7 DAT, 10 DAT), respectively. Data was analyzed with analysis of variance and means were separated using a Duncan's new multiple range test ($P < 0.10$).

Results and Discussion

Soybean looper densities in the untreated check ranged from 50 to 16.6/25 sweeps, 3 and 10 DAT, respectively (Table 1). At 3, 7, and 10 DAT, all treatments reduced SBL densities when compared to the UTC. Prevathon® delivered the greatest control of SBL at 3, 7, and 10 DAT, but was no different than ChinNPV 1.4 or 5.6 oz/acre at 10 DAT.

Two of the tested ChinNPV rates provided a similar amount of control of SBL when compared to Prevathon at 10 DAT. In order for ChinNPV to be an effective control option, it will likely need to be applied in the early stages of SBL infestation which is similar to how other viral insecticides must be used. More research needs to be conducted on how to best use ChinNPV; however it shows promise, particularly with the current state of insecticide resistance in SBL, as an effective control option for SBL in Arkansas soybean.

Practical Applications

This research evaluated the efficacy of ChinNPV as a control option for SBL. Soybean looper has become increasing harder to control due to insecticide resistance. When the diamide class of chemistry was first introduced, it gave growers a new tool to effectively control SBL. However in recent years, a decline in efficacy has been observed with diamides for control of SBL. The new ChinNPV will effectively give growers a new tool to combat SBL. More research is need to determine the best application timing and rate for ChinNPV.

Acknowledgements

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Table 1. Effect of selected insecticides on soybean looper at multiple sample dates.

		Soybean Loopers/25 sweeps		
Product/ Formulation	**Rate (oz product/acre)**	**2-Sep 3 DAT**	**6-Sep 7 DAT**	**9-Sep 10 DAT**
UTC		50.0a	38.2a	16.6a
*Chin*NPV 7.5 × 10^9 OB/ml	0.7	33.1b	14.9b	3.1b
*Chin*NPV 7.5 × 10^9 OB/ml	1.4	32.5b	14.0b	2.0bc
*Chin*NPV 7.5 × 10^9 OB/ml	2.8	34.2b	17.9b	3.1b
*Chin*NPV 7.5 × 10^9 OB/ml	5.6	35.0b	14.1b	2.0bc
*Chin*NPV 7.5 × 10^9 OB/ml + Heligen 7.8 × 10^8 OB/ml	1.4 + 1.4	29.2b	12.5b	4.1b
Prevathon 0.43 SC	14	0.0c	1.0c	0.4c
P-Value		<0.01	<0.01	<0.01

*Chin*NPV = *Chrysodeixis includens* nucleopolyhedrovirus.
Means within a column followed by the same letter do not differ statistically according to Duncan's new multiple range test ($P < 0.10$).
UTC = untreated check; DAT = days after treatment.

Evaluating Growth Stage Sensitivity of Soybean to Redbanded Stink Bugs

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Abstract

Experiments were conducted in 2017 to determine differences in soybean growth stage sensitivity to redbanded stink bug feeding. Redbanded stink bug were caged on individual soybean pods at multiple growth stages spanning from R5 through R7. The R5 infestation timing had the highest damaged seed rating and lowest seed weight. There was no difference observed between the R7 infestation timing and the untreated control.

Introduction

Redbanded stink bug are not a perennial pest of soybean in Arkansas (Musser et al., 2013); but during the 2017 growing season, soybean producers throughout most of the state experienced high infestations of redbanded stink bugs. Initial infestations in the southern part of Arkansas were in late reproductive stage soybean. As the growing season progressed, redbanded stink bugs were observed in all reproductive stages of soybean. Large amounts of seed damage (quality loss) was observed from redbanded stink bug feeding. Although the potential damage of redbanded stink bug has been documented (Vayvhare et al., 2015), knowing which growth stages are the most sensitive to redbanded stink bug feeding is critical for adjusting thresholds and keeping growers profitable.

Procedures

Experiments were conducted at the University of Arkansas System Division of Agriculture's Rohwer Research Station to determine growth stage sensitivity of soybean to redbanded stink bug feeding. At the R4.5 growth stage, a small mesh cage and wire, following the design of Campos et al. (2010), was used to cage redbanded stink bugs on individual soybean pods. Infestations of redbanded stink bug were made at the R5, R5.5, R6, R6.5, and R7 growth stages, with 10 replications of each infestation timing. Infested cages were examined every 8 hours to ensure redbanded stink bug survival, and infestations were terminated after 48 hours by removing the redbanded stink bug. At the R8 growth stage, pods were examined for redbanded stink bug feeding. A measure of seed damage was taken on a 1 to 5 scale, with 1 being no damage and 5 being no seed. All data was analyzed with analysis of variance in PROC GLIMMIX (SAS version 9.4, SAS Institute, Cary, N.C.) with an alpha level of 0.05.

Results and Discussion

Differences among infestation timings were observed for average seed weight ($P < 0.01$). The untreated control and R7 infestation timing had a greater average seed weight than all other infestation timings (Table 1). The R5 and R5.5 infestation timings had the lowest average seed weight when compared to all other infestation timings (Table 1). A similar trend was observed for the damaged seed ratings, with the R5 infestation timing having the highest seed damage rating (Table 1). The R7 infestation timing and the untreated control had the lowest seed damage rating (Table 1).

Practical Applications

Growers must be reactive with redbanded stink bug in the early reproductive stages of soybean. This is a critical time where redbanded stink bugs can not only cause massive yield and quality loss, but can also delay maturity. Based on these studies, the R7 growth stage can tolerate more redbanded stink bug feeding without yield or quality loss than earlier growth stages, therefore current thresholds during the late reproductive stages will be raised.

Acknowledgements

The authors would like to thank the Arkansas Soybean Promotion Board for their support of this research. Support was also provided by the University of Arkansas System Division of Agriculture.

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Table 1. Average seed weight and damaged seed rating for multiple infestation timings of redbanded stink bug in soybean.

Infestation Growth Stage	Average Seed Weight (G)	Damaged Seed Rating (1 = No Damage; 5 = No Seed)
R5	0.00 d[†]	5.0 a
R5.5	0.02 d	4.0 b
R6	0.05 c	3.5 c
R6.5	0.09 b	2.9 d
R7	0.13 a	1.7 e
Untreated Control	0.12 a	1.5 e
P-Value	<0.01	<0.01

[†] Means followed by the same letter do not differ significantly as analyzed by analysis of variance in PROC GLIMMIX.

Determining Late-Season Thresholds for Redbanded Stink Bugs

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Abstract

Experiments were conducted in 2017 to evaluate when insecticide applications can be terminated for redbanded stink bug on soybean. Varying densities of redbanded stink bugs were infested in mesh field cages at the R7 and R8 growth stages. No yield loss was observed at any of the tested infestation levels. However, a greater percentage of damaged seed was observed in the R7 growth stage when exposed to the highest infestation level of redbanded stink bug, but these differences were not observed in soybean at the R8 growth stage.

Introduction

Redbanded stink bug is a major pest of soybean in the mid-South (Vyavhare et al. 2015). However, in Arkansas, this pest is not an annual problem (Musser et al., 2013). Due to mild winters in 2015 and 2016, redbanded stink bug was able to successfully overwinter in Arkansas. Since redbanded stink bug is not a perennial pest in Arkansas soybean, there has been little data generated within the state other than efficacy of insecticides. One of the major questions that occurred during the 2017 growing season was, when can growers stop making insecticide applications for this pest without the risk of yield and quality loss? A large percentage of the soybean acreage in south Arkansas received multiple applications for redbanded stink bug, with some of these applications occurring at the R7 to R8 growth stage. Knowing when we can safely terminate these applications will make soybean producers in Arkansas more profitable.

Procedures

Experiments were conducted at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station and Northeast Research and Extension Center to determine when insecticide applications can be terminated for redbanded stink bug. Mesh field cages, measuring 6 ft × 6 ft × 5 ft were used to establish plots when the soybean reached the R6.5 growth stage. Varying densities of redbanded stink bug, ranging from 0 to 32 redbanded stink bug per 25 sweeps, were placed into field cages at the R7 and R8 growth stages. Cages were inspected every two days to confirm that the redbanded stink bugs were still alive while replacing any that were found dead. Infestations were maintained until harvest. At harvest, 5 plants were examined and percent damaged seed was assessed. Yield was also recorded using a plot combine. All data was analyzed with analysis of variance in PROC GLIMMIX (SAS version 9.4, SAS Institute, Cary, N.C.) with an alpha level of 0.05.

Results and Discussion

No differences in yield were observed for any infestation level at the R7 ($P = 0.01$) (Fig. 1) or R8 ($P = 0.64$) (Fig. 2) infestation timing. Differences were observed however, for percent damaged seed ($P < 0.01$) at the R7 infestation timing. The infestation density of 32 redbanded stink bug per 25 sweeps had a higher percentage of damaged seed compared to all other infestation levels (Fig. 3). No differences in percent damaged seed ($P = 0.40$) were observed for the R8 infestation timing (Fig. 4).

Practical Applications

Although redbanded stink bug are not a perennial pest of soybean in Arkansas, knowing when insecticide applications for this pest can be terminated will save soybean producers money. Based on the results of these termination studies, the current thresholds for redbanded stink bug will be adjusted in 2018, moving from 4 per 25 sweeps to 10 per 25 sweeps at the R6.5 growth stage with termination of insecticides at R7.

Acknowledgements

The authors would like to thank the Arkansas Soybean Promotion Board for their support of this research. Support was also provided by the University of Arkansas System Division of Agriculture.

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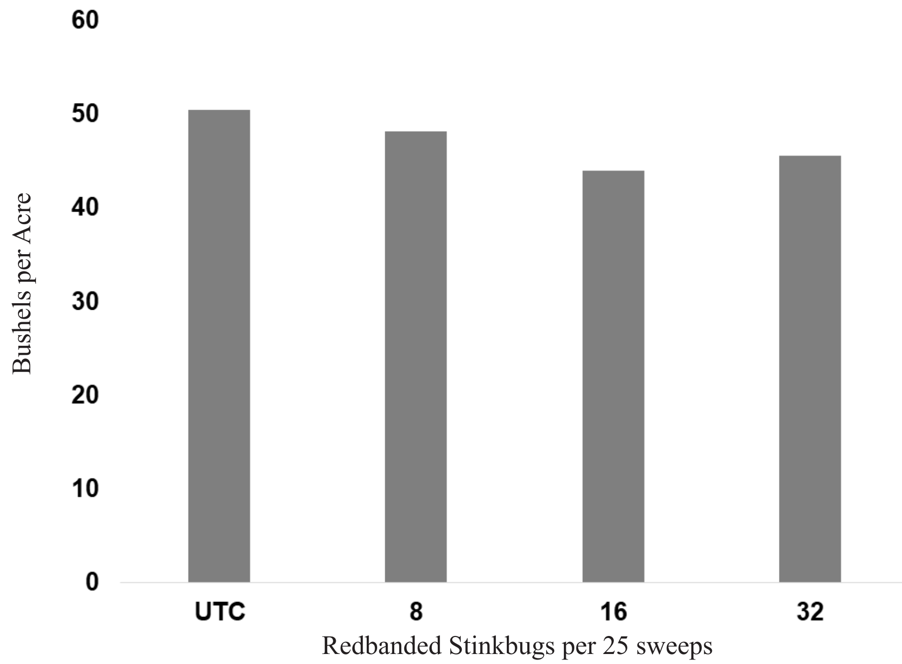

Fig. 1. Yield for redbanded stink bug infestations in soybean at the R7 growth stage.

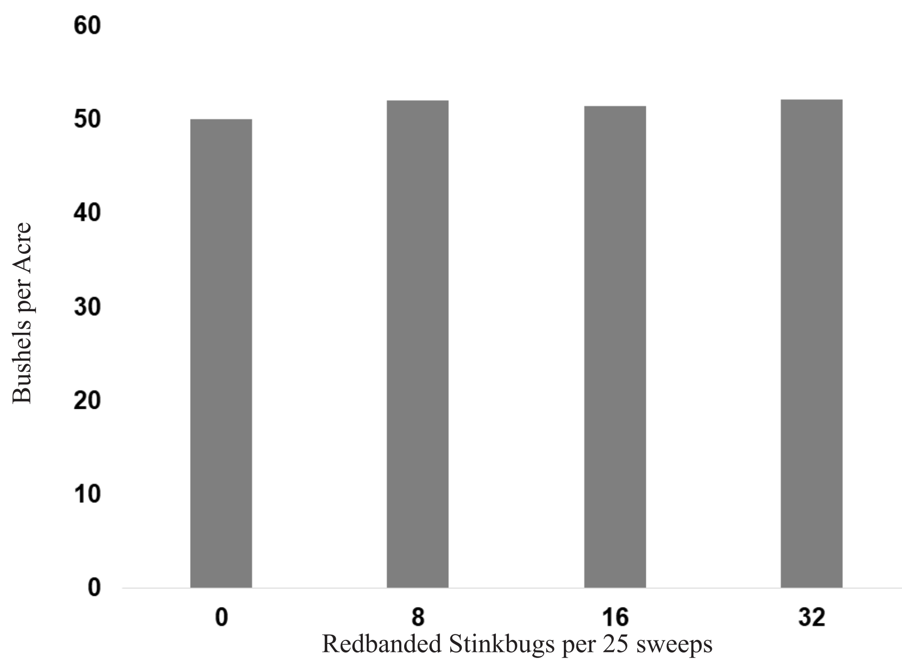

Fig. 2. Yield for redbanded stink bug infestations in soybean at the R8 growth stage.

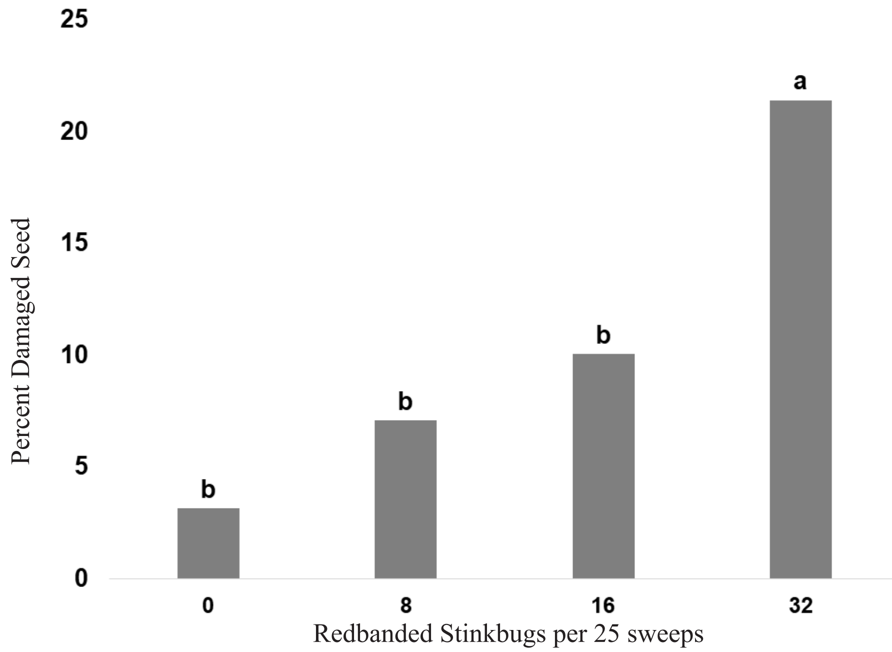

Fig. 3. Percent damaged seed for redbanded stink bug infestations in soybean at the R7 growth stage.

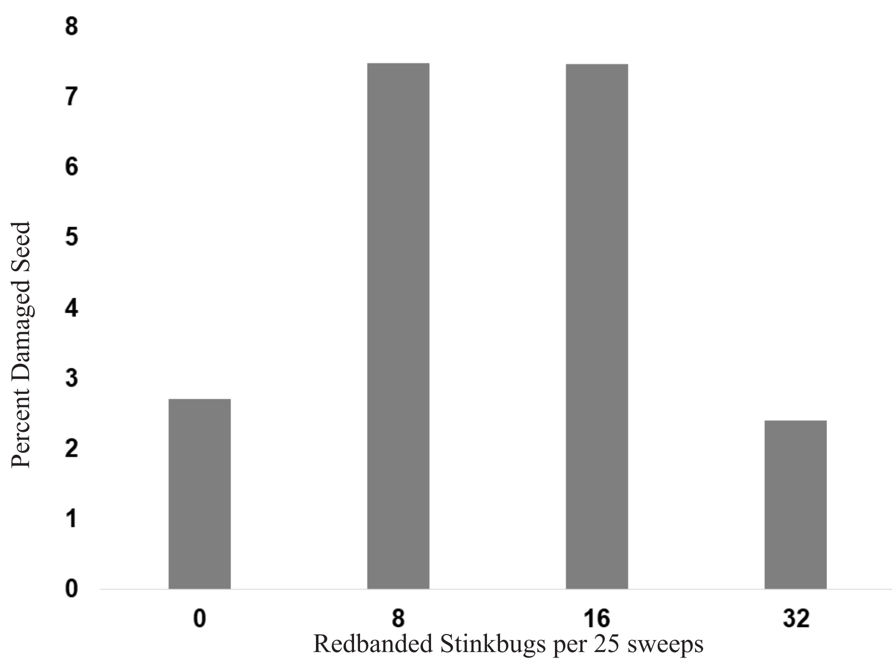

Fig. 4. Percent damaged seed for redbanded stink bug infestations in soybean at the R8 growth stage.

Efficacy of Selected Insecticides for Control of Redbanded Stink Bug

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Abstract

A trial was conducted in 2017 to evaluate selected insecticides for control of redbanded stink bug. At 6 and 10 days after the first application, all treatments reduced redbanded stink bug densities when compared to the untreated check (UTC). At 4 and 10 days after the second application, all treatments continued to have densities lower than the UTC. In general, treatments using multiple modes of action provided greater control of redbanded stink bug than treatments with a single mode of action.

Introduction

Redbanded stink bug (RBSB), *Piezodorus guildinii* Westwood, is an occasional pest of soybean in Arkansas but can cause serious damage to soybean when present. The RBSB has poor cold tolerance due to its tropical origin so winter temperatures typically eliminate the insect from Arkansas and down to the deep southern U.S. such as lower Louisiana (Akin et al., 2011). Mild winters, as was the case in 2016 and 2017, allow this pest to survive farther north than usual, allowing it to move into the state (McGeeney 2017). Early planting is the best way to avoid RBSB, however this is not always possible and insecticides must be used for control. This test evaluates the efficacy of several insecticides for control of RBSB.

Procedures

A trial was conducted on a grower field in Marianna, Arkansas to evaluate the efficacy of selected insecticides to control RBSB in soybean. Plot size was 4 rows by 50 feet long planted on 38-inch rows, arranged in a randomized complete block design with 4 replications. Soybean was planted on 25 May. Insecticides were applied with a Mud-Master sprayer equipped with a multi-boom delivering 10 gpa at 40 psi through 80-02 dual flat fan nozzles with a 19.5-in. spacing. Insecticide application occurred on 27 Sept. and was applied again to the same plots on 6 October. The RBSB densities were determined by taking 25 sweeps per plot with a 15-in. diameter net. Samples were taken on 27 Sept. and 2 Oct., 6 and 11 days after the first application (6 DAT1 and 11 DAT1) and on 10 Oct. and 16 Oct., 4 and 10 days after the second application (4 DAT2 and 10 DAT2), respectively. Data was analyzed with analysis of variance and means were separated using a Duncan's new multiple range test ($P < 0.10$).

Results and Discussion

The RBSB densities ranged from 41 to 124/25 sweeps in the untreated check (UTC) throughout the duration of the trial, well above the current economic threshold (ET) of 4 RBSB/25 sweeps (Table 1). All treatments reduced RBSB densities compared to the UTC but none reduced RBSB densities below the ET after the first application. After the second application, Leverage 360 was the only treatment to provide enough control to reduce RBSB densities below the ET, but was not different than any other treatment except Bifenthrin at 6 oz/ac. Bifenthrin at 6 oz/ac plus Belay® at 3 oz/ac had fewer total RBSB than all applications with a single mode of action. In general, treatments with multiple modes of action performed better than those containing a single mode of action.

Practical Applications

These data, along with efficacy studies conducted in previous years with high populations of RBSB, suggest that application of two modes of action will provide better control and a longer residual than single mode of action products. This in turn can help growers protect yield while making less applications.

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Table 1. Effect of selected insecticides on redbanded stinkbug at multiple sample dates.

		Redbanded Stink Bugs/25 sweeps				
Product/ Formulation	**Rate (oz product/acre)**	**27-Sept. 6 DAT1**	**2-Oct. 11 DAT1**	**10-Oct. 4 DAT2**	**16-Oct. 10 DAT2**	**Season Total**
UTC		40.6a[†]	123.8a	72.5a	111.7a	358.8a
Silencer 1 EC	3.7	17.5bc	58.1bcd	16.7bc	23.8bcd	115.8c
Bifenthrin 2 EC	3.2	28.3b	62.5bc	14.2bc	34.4b	157.5b
Bifenthrin 2 EC	6	23.1bc	30.8ef	25.6b	37.5b	103.3cde
Bifenthrin 2 EC +	6					
Imidacloprid 4 F	3	18.3bc	72.5b	8.8c	12.5d	110.8cd
Bifenthrin 2 EC +	6					
Orthene 97	8	11.7c	29.2f	5.8c	25.6bcd	71.7de
Bifenthrin 2 EC +	6					
Belay 2.13	3	13.1c	37.5def	5.0c	13.8d	69.4e
Orthene 97	16	13.3c	51.9b-e	12.5bc	28.1bcd	107.5cde
Endigo ZC 2.06	4.5	13.8c	30.6ef	17.5bc	31.9bc	93.75cde
Leverage 360	3.2	13.3c	45.0c-f	3.1c	16.3cd	74.2de
P Value		<0.01	<0.01	<0.01	<0.01	<0.01

[†] Means within columns followed by the same letter are not significantly different according to Duncan's new multiple range test ($P < 0.10$).

Monitoring Residual Herbicide Concentrations in a Tailwater Recovery System in the Cache Critical Groundwater Zone

C. Willett[1], E. Grantz[1], D. Leslie[2], and M. Reba[3]

Abstract

To address rapid aquifer decline in groundwater depletion zones, producers have begun incorporating tailwater recovery into irrigation systems. Water-saving benefits of on-farm reservoirs have been explored, but less is known about how these systems affect water quality or about the persistence and accumulation of herbicides within them. This study initiated a herbicide monitoring record for a tailwater recovery system (one reservoir and three ditches), collecting samples weekly during the growing season (April-August 2017). Of seven target herbicides [2,4-D, clomazone (e.g. Command®), dicamba (e.g. Clarity®), glyphosate (e.g. RoundUp®), metolachlor (e.g. Dual®), propanil (e.g. Stam®), and quinclorac (e.g. Facet®)], clomazone, glyphosate, metolachlor, and quinclorac were frequently detected. These herbicides exhibited a spring flush, and peak concentrations coincided with heavy precipitation in the region. Herbicide concentrations were more variable and higher, on average, in the ditches than in the reservoir. Data from this study can be used to screen tailwater for herbicide concentrations that could lead to cross-crop injuries, to characterize reservoir water quality for suitability for artificial groundwater recharge, and to estimate herbicide loads intercepted by tailwater recovery systems.

Introduction

Water levels in agriculturally important aquifers in Arkansas have declined at unsustainable rates in recent decades (Schrader, 2015; Reba et al., 2017). In groundwater depletion zones, such as the Cache Critical Groundwater Area, producers have begun incorporating tailwater recovery into irrigation systems by constructing networks of ditches and storage reservoirs (Fugitt et al., 2011; Yaeger et al., 2017). Ditches recapture runoff and tailwater leaving fields, while reservoirs provide capacity to store tailwater and winter-spring precipitation for growing season irrigation supply. The water-saving benefits of on-farm reservoirs have been established, potentially replacing 25–50% of groundwater irrigation (Sullivan and Delp, 2012). Less is known about how these systems affect water quality in the surrounding landscape or about the persistence and accumulation of herbicides within them.

Tailwater recovery systems also offer the potential benefit of conserving water quality in adjacent surface waters by reducing off-site movement of nutrients, sediment, and herbicides through retention and transformation processes. Further, water stored in reservoirs has been proposed as suitable supply for managed aquifer recharge (Reba et al., 2015; Reba et al., 2017). Tailwater reuse also poses risks of cross-crop impacts if herbicide residues are present in irrigation water at levels that could injure non-target crops, and any recharge supply must meet water quality standards. This study initiated a herbicide monitoring record for a tailwater recovery system (Fig. 1) located in the Cache Critical Groundwater Area to assess potential water quality issues from tailwater reuse.

Procedures

Water samples were collected weekly from an on-farm reservoir and three associated tailwater ditches during April–August 2017. The reservoir was 65 ac, with north-south orientation, in Calhoun and Tichnor silt loam, with recycled rock banks, and supplied and received water to and from surrounding fields, planted primarily in rice and soybean. Upon study initiation in April 2017, herbicide application records were collected from the producer and were updated throughout the growing season. Based on this information, broad frequency of use, and anticipated future use, seven herbicides were selected as target herbicides: 2,4-D, clomazone (e.g. Command®), dicamba (e.g. Clarity®), glyphosate (e.g. RoundUp®), metolachlor (e.g. Dual®), propanil (e.g. Stam®), and quinclorac (e.g. Facet®). Meteorological data (weatherdata.astate.edu) were collected from a station on the Arkansas State University campus located about 7.5 miles northeast of the sample site. Precipitation was measured using a Campbell Scientific TB4 tipping bucket gauge (www.campbellsci.com; Logan, Utah).

Grab samples were collected in high density polyethylene bottles, stored on ice, and shipped overnight for processing

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by the University of Arkansas System Division of Agriculture's Residue Laboratory at Fayetteville. Samples were stored at 39 °F until filtration through a 0.45 µm nylon membrane within 48 hours. Filtered samples were preserved by freezing after separating into aliquots for 1) glyphosate analysis using enzyme-linked immunosorbent assay (ELISA) or 2) analysis of all other target herbicides by high performance liquid chromatography with photodiode array detection (HPLC-DAD) following solid phase extraction (SPE). A total of 17, 16, 19, and 19 samples were analyzed from the Ditch 2, Ditch 3, Ditch 5, and reservoir sample locations, respectively (Fig. 1).

Glyphosate analysis followed standard procedures for ELISA, and measured concentrations directly represent tailwater concentrations. Aliquots for other target herbicides were concentrated by SPE from 200 mL to 8 mL 50:50 acetonitrile:methanol eluates using Strata-X reverse-phase polymer columns. Eluates were spiked to a known concentration with 100 mg/L metazachlor to correct for volumetric variability and were analyzed using HPLC-DAD with a mobile phase gradient of acetonitrile in 0.1% phosphoric acid ranging from 34–64% over 20 min. Target analytes were monitored at wavelengths that maximized absorption intensity. Tailwater herbicide concentrations were calculated by multiplying the concentration measured on HPLC by the ratio of the eluate and beginning sample volumes after correcting eluate volume for differences in the measured and expected metazachlor concentration.

Results and Discussion

Clomazone, glyphosate, metolachlor, and quinclorac were frequently detected in the tailwater recovery system from April–August 2017 (Table 1). These herbicides exhibited a spring flush, with concentrations peaking in April–early July (Fig. 2), coinciding with heavy precipitation in the region (Fig. 3). Concentrations of clomazone and quinclorac, applied earliest in the season, peaked in April–late June, with no remaining or only low level detections by August. Concentrations of glyphosate and metolachlor, applied later in the season, peaked in late June–early July and exhibited a second flush, likely due to heavy precipitation in August.

Herbicide concentrations were more variable and higher, on average, in the ditches than in the reservoir (Table 1). This finding is congruent with the concept that residues break down over time and are diluted along the flow path by mixing with increasingly large volumes of water. Findings are also congruent with previous reports from regional tailwater systems and river networks (Dewell and Lavy, 1996; Mattice et al., 2010). However, in late June–early July and again in August, reservoir glyphosate and metolachlor concentrations were notably more variable. In fact, in late August, maximum reservoir concentrations were comparable with ditches. However, at that time, metolachlor ditch concentrations were as low as 25% of maximum levels. Also, reservoir concentrations for any of the detected herbicides never exceeded 10 µg/L, while ditch concentrations frequently did.

Practical Applications

Data from this study can be used to screen recovered tailwater for herbicide concentrations that could lead to cross-crop injuries during the growing season, characterize quality of water stored in tailwater systems in terms of suitability for artificial groundwater recharge, and estimate herbicide loads intercepted by tailwater recovery systems. Study findings support the following recommendations to minimize risk of cross-crop contamination when using recovered tailwater for irrigation: 1) source irrigation water only out of reservoirs and 2) always cycle recovered tailwater through the reservoir for treatment of residual herbicides. Before it can be determined if any of the concentrations detected represent high-risk events for cross-crop contaminations, more information is needed about how common crops like soybean, rice, or cotton respond to off-target exposure to herbicide residues in irrigation water across a range of concentrations. Study findings support the focus of non-growing season use of on-farm reservoirs as a water supply in managed aquifer recharge strategies such as infiltration galleries, as the periodically elevated concentrations of herbicide residues during the growing season may be of relevance to regulatory bodies. Continued work on the project will assess the non-growing season herbicide concentrations in the on-farm storage reservoir. Additional edge-of-field monitoring under the Mississippi River Basin Healthy Watershed Initiative is being carried out through USDA-Natural Resource Conservation Service to assess the effect of irrigation water management practices on water quality, specifically concerns related to suspended sediment concentrations in runoff.

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Acknowledgements

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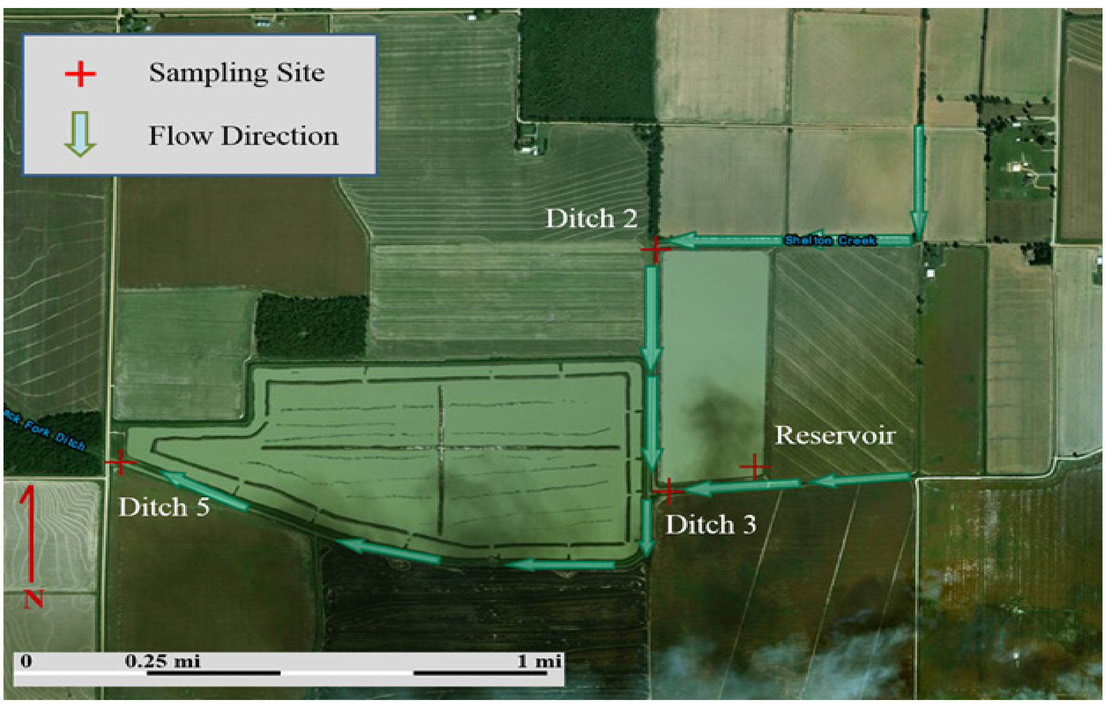

Fig. 1. Map of the monitored tailwater recovery system in Craighead County, Arkansas.

Table 1. Summary statistics for clomazone, glyphosate, metolachlor, and quinclorac concentrations measured in ditches and reservoir during April–August 2017 in the monitored tailwater recovery system in the Cache Critical Groundwater Area.

Herbicide	Site	Median (µg/L)	Mean (µg/L)	Standard Deviation (µg/L)	Range (µg/L)
Clomazone	Ditch 2	ND	0.04	0.16	0.64
	Ditch 3	ND	0.50	1.00	3.00
	Ditch 5	ND	0.53	1.29	5.29
	Reservoir	ND	ND	ND	ND
Glyphosate	Ditch 2	0.38	0.56	0.55	1.76
	Ditch 3	0.33	0.66	0.88	3.48
	Ditch 5	0.32	0.69	1.01	3.53
	Reservoir	0.12	0.30	0.42	1.59
Metolachlor	Ditch 2	ND	2.96	5.65	21.90
	Ditch 3	0.51	2.34	4.39	17.45
	Ditch 5	ND	1.58	3.95	15.01
	Reservoir	ND	0.60	0.86	2.10
Quinclorac	Ditch 2	0.75	0.70	0.52	2.00
	Ditch 3	1.44	2.29	2.99	12.72
	Ditch 5	1.22	2.98	5.07	21.94
	Reservoir	0.96	0.97	0.09	0.34

ND indicates that the herbicide was not detectable.

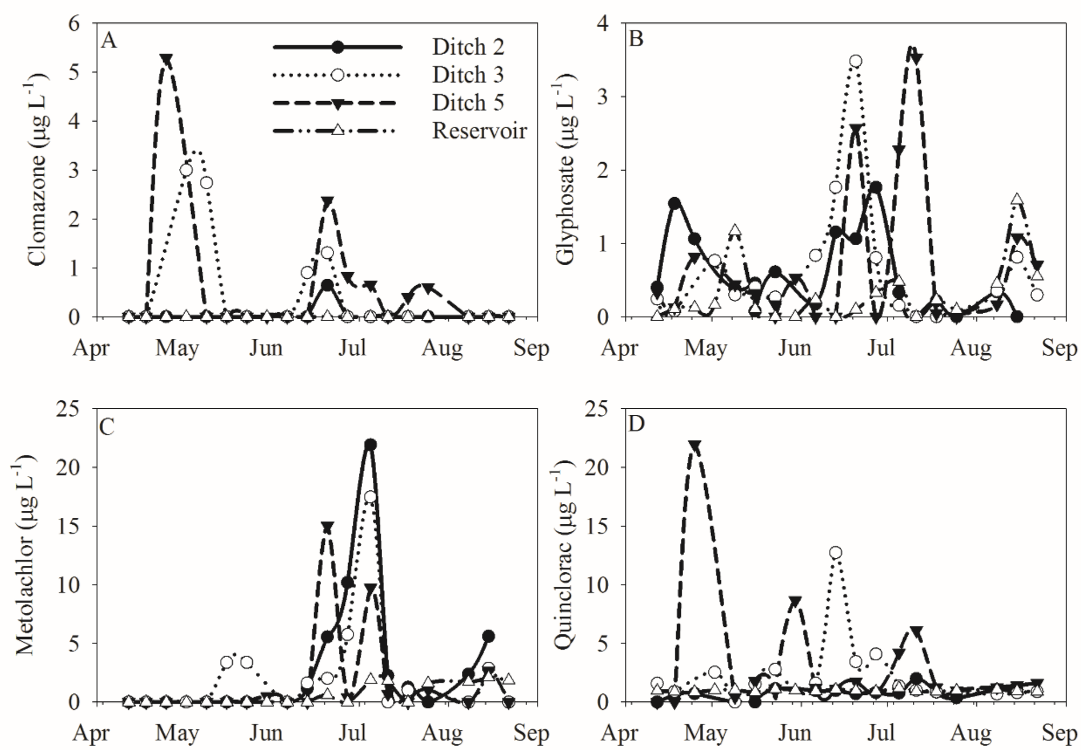

Fig. 2. Monthly precipitation measured in Craighead County, Arkansas during April – August 2017 and U.S. precipitation normals for the region averaged over 30 years between 1981-2010 (NOAA, 2018).

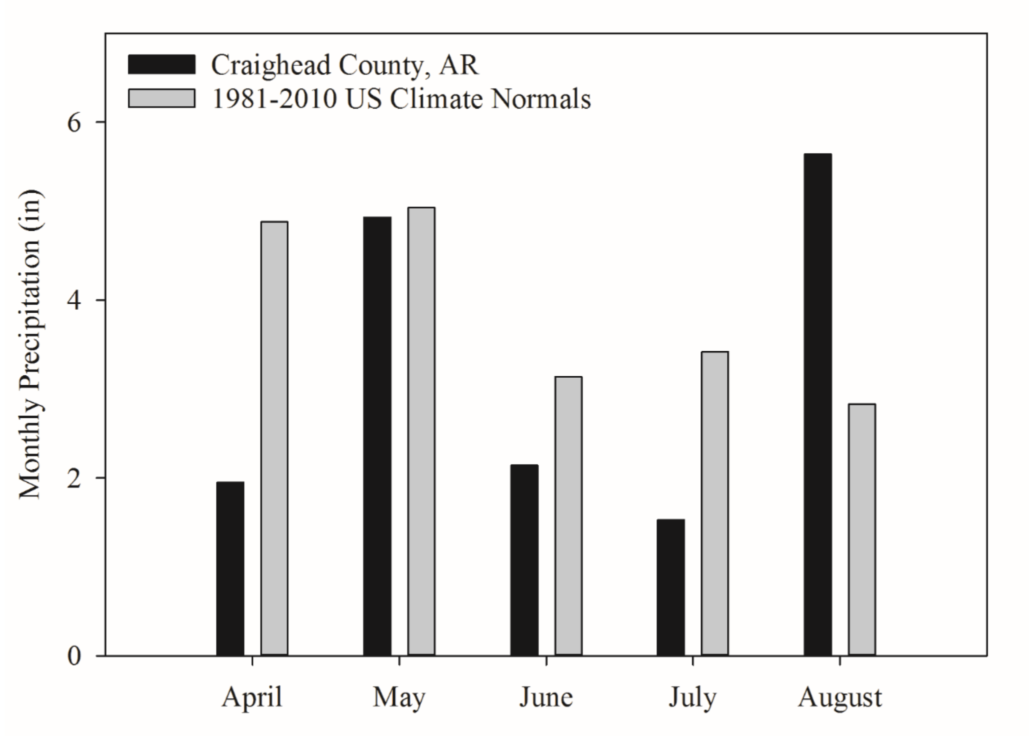

Fig. 3. Monthly precipitation measured in Craighead County, Arkansas during April–August 2017 and U.S. precipitation normals for the region averaged over 30 years between 1981 and 2010 (NOAA, 2018).

Economic Analysis of the 2017 Arkansas Soybean Research Verification Program

C.R. Stark, Jr.[1]

Abstract

Economic and agronomic results of a statewide soybean research verification program can be a useful tool for producers making production management decisions prior to and within a crop growing season. The 2017 season results indicate that yields can be increased approximately 50% by the use of irrigation. A Roundup Ready©/furrow irrigation system generated the highest average revenue. Center pivot systems had the lowest average Variable Costs and highest average Fixed Costs. Return to Land and Management was much higher for the fields using a Roundup Ready/furrow irrigation system.

Introduction

The Arkansas Soybean Research Verification Program (SRVP) originated in 1983 with a University of Arkansas System Division of Agriculture's Cooperative Extension Service (CES) study consisting of four irrigated soybean fields. Records have been compiled each succeeding year from the fields of participating cooperators until over 500 individual fields now comprise the state data set. Among other goals, the program seeks to validate CES standard soybean production recommendations and demonstrate their benefits to state producers. Studies of the annual program reports have shown that SRVP producers consistently exceed the state average soybean yields, even as both measures have trended upward (Stark, et al., 2008). Specific production practice trends have also been identified using the SRVP database such as herbicide use rates (Stark et al., 2011). Cooperating producers in each yearly cohort are identified by their county extension agent for agriculture. Each producer receives timely management guidance from state SRVP coordinators on a regular basis and from state extension specialists as needed. Economic analysis has been a primary focus of the program from the start. The SRVP coordinators record input rates and production practices throughout the growing season including official yield measures at harvest. A state extension economist compiles the data into the spreadsheet used for annual cost of production budget development. Measures of profitability and production efficiency are calculated for each cooperator's field and grouped by soybean production system.

Procedures

Sixteen cooperating soybean producers from across Arkansas provided input quantities and production practices utilized in the 2017 growing season. A state average soybean market price was estimated by compiling daily forward booking and cash market prices for the 2017 crop. The collection period was January 1 through October 31 for the weekly soybean market report published on the Arkansas Row Crops Blog (Stark, 2017). Data was entered into the 2017 Arkansas soybean enterprise budgets for each respective production system (Flanders, 2017). Input prices and production practice charges were primarily estimated by the Flanders budget values. Missing values were estimated using a combination of industry representative quotes and values taken from the Mississippi State Budget Generator program for 2017 (Laughlin and Spurlock, 2016). Summary reports, by field, were generated and compiled to generate system results.

Results and Discussion

The 16 fields in the 2017 Arkansas Soybean Research Verification Program report spanned 6 different production/irrigation systems (Table 1; Elkins, 2017). Half of the system combinations utilized Roundup Ready© (RR) technology seed. Two systems used Liberty Link© (LL) seed and the final system had conventional seed. Half of the fields were grown under a Roundup Ready system with furrow irrigation. Four other fields employed furrow irrigation, two fields had center pivot irrigation, and two fields were non-irrigated. The small numbers of fields represented in this study do not permit standard statistical analysis. Yield and economic results are presented by grouping only for discussion purposes.

Yields by system ranged from 34.4 to 68.9 bu/ac. Weighted average yield per field across all systems was 59.4 bu/ac. Irrigation was clearly a differentiating factor with the irrigated fields averaging 62.0 bu/ac versus non-irrigated averaging 41.3 bu/ac. The highest system yield was 68.9 bu/ac for the RR/furrow irrigation system. All yields were standardized to 13% moisture content.

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Soybean forward book and cash market price for the 2017 crop averaged $11.21 per bushel over the period of 1 Jan. – 31 Oct. 2014. Market price multiplied by yield gave field revenues. No grade reductions or premiums were included. Highest average revenue per acre was $771.88 for the RR/furrow irrigation system.

Variable Costs across all systems had a weighted average of $277.22 and ranged from $183.77 to $311.17 per acre. Lowest Variable Cost totals were seen in the center pivot systems. Fixed Costs across all systems had a weighted average of $60.40 and ranged from $50.73 to $82.43 per acre. Highest Fixed Costs, as expected, were found in the center pivot systems.

Combination of the Variable Costs and Fixed Costs with Revenue values allowed calculations of Returns to Land and Management. The weighted average of Return to Land and Management across all fields was $328.08 per acre. The RR/furrow irrigation system generated a Return to Land and Management that was much higher than other system combinations with an average of $431.71 per acre. The two non-irrigated fields had an average Return to Land and Management of only $109.76 per acre.

Practical Applications

The results of state research verification programs can provide valuable information to producers statewide. Illustration of the returns generated when optimum management practices are applied can facilitate the distribution of new techniques and validate the standard recommendations held by state row-crop production specialists. Adoption of these practices can benefit producers currently growing soybeans and those contemplating production.

Acknowledgements

The author wishes to thank the Arkansas Soybean Promotion Board, University of Arkansas System Division of Agriculture, and the University of Arkansas at Monticello School of Agriculture who provided funding and other support for this research project. Appreciation is also extended to Chad Norton and Chris Elkins, Arkansas Soybean Research Verification Program Coordinators, and Jeremy Ross, Arkansas Soybean Research Verification Program Director, without whom this research would not have been possible.

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Table 1. Soybean Research Verification Program economic results by production/irrigation system, 2017

Production System Irrigation System	Early-Season Irrigated	Full-Season Irrigated	Early-Season Non- Irrigated	Full-Season Non-Irrigated
# Fields	8	2	1	3
Yield (bu./ac)	68.9	41.3	42.7	56.13
Revenue ($/ac)	771.88	462.98	412.48	631.69
Total Variable Costs ($/ac)	281.07	302.49	191.37	311.17
Total Fixed Costs ($/ac)	59.10	50.73	52.88	63.71
Total Costs ($/ac)	340.17	353.22	244.25	374.88
Returns to Land & Management ($/ac)	431.71	109.76	168.23	256.81

Source: 2017 Arkansas Soybean Research Verification Program Report.

Commodity Program Analysis of Arkansas Representative Farms, 2016-2023

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Abstract

Current commodity programs, authorized in Title 1 of the Agricultural Act of 2014 (also known as the 2014 Farm Act) will expire in 2018. New legislation will replace the 2014 farm bill. This study assesses the adequacy of the Price Loss Coverage (PLC) program and payment limit provisions of current law, if they are extended in the new farm bill. The analysis includes five representative Arkansas farms. The production and financial characteristics of these farms are projected for 2017 to 2023. The adequacy of government commodity support from the reference price of the PLC relative to costs of production is evaluated. Except for peanuts, the current level of PLC supports are not adequate to cover costs of production for soybean, rice, corn and cotton. Payment limit provisions of the current farm bill, if extended, will also adversely affect Arkansas crop farms.

Introduction

In this study, the focus is on the financial status of five representative Arkansas crop farms in Stuttgart, Wynne, McGehee, Mississippi County, and Hoxie for the seven-year period starting from 2017 through 2023, which covers the last two years of the current farm bill and the expected five years (2019-2023) of a new farm bill. The adequacy of commodity program support for the primary Arkansas crops, with a focus on soybean is evaluated. As the largest row crop in Arkansas exceeding the acreage of rice, corn, sorghum and wheat combined, soybean plays a substantial role in the state's economy. Soybean and soybean products are Arkansas' largest agricultural exports (Arkansas Farm Bureau, 2018). We also examine the likelihood that payment limit provisions in the current farm bill will adversely impact Arkansas crop farms. Projected prices and costs generate estimates of future Arkansas net cash farm income and the role of commodity support programs in sustaining these farms.

Procedures

The five representative farms are based on financial data files made available by the Texas A&M Agricultural and Food Policy Center (AFPC). The AFPC develops and maintains data to analyze 94 representative crop, dairy, and livestock operations in major production areas in 29 states—with a stated purpose of projecting the economic viability of these farms. Baseline data are developed through ongoing cooperation with panels of agricultural producers in the selected states (Richardson et al., 2017). The five Arkansas farms covered in this paper are included in the AFPC portfolio of representative farms. The 2016 data for Arkansas farms were developed with panels of farmers with the participation of the University of Arkansas System Division of Agriculture research and extension personnel. This data was extended for the years 2017-2023 based on currently available information specific to the state—notably prices and various costs including input costs, drying costs, and the costs of machinery and equipment. The updated input cost projections are based on the August 2017 baseline of the Food and Agricultural Policy Research Institute (FAPRI/University of Missouri).

Results and Discussion

Farm Descriptions. The basic characteristics for each of the five farms in terms of acreage and crop mix are presented in Tables 1 through 5. The Stuttgart farm includes a total of 3,240 acres comprising 45% soybeans, 45% long-grain rice, and 10% corn. The Wynne farm operates 2,500 acres equally split between irrigated soybeans and long-grain rice. The McGehee farm is the largest of the five farms with a total of 6,500 acres with 60% planted to full-season soybean, 30% to corn and 10% to long-grain rice. The Mississippi County farm produces on 5,000 acres with 50% irrigated cotton/cottonseed, 20% soybean, 20% peanuts, and 10% corn. The Hoxie farm has 4,000 acres with 51% long-grain rice, 30.6% irrigated soybeans, 9% medium-grain rice, 6.3% corn, and 3.1% dry soybeans. Each farm has acreage allocated by percent owned, percent cash rented, and percent share-rented. By subtracting out landlord share, the effective base and planted acres that generates the revenue and costs for the farm operator can be calculated.

Two key issues are of concern to Arkansas crop producers with respect to the development of the Commodity Title in the 2018 Farm Bill. The first issue is whether reference prices associated with the Price Loss Coverage (PLC) program can provide adequate support should market prices continue to be weak, resulting in net cash farm income losses. The second issue relates to the fact that most Arkansas crop farms are relatively large compared to mid-west farms

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and that the payment limit provisions in the commodity title are not sufficient to sustain Arkansas farms when the farm economy is weak.

Baseline Costs of Production Relative to Reference Prices. Arkansas producers are expected to enroll heavily in the Price Loss Coverage (PLC) in the next farm bill. While many Arkansas soybean and corn producers enrolled in the Agriculture Risk Coverage-County (ARC-Co) program under the 2014 Farm Act, historical prices relative to projected prices suggest that the ARC-Co program will not provide adequate commodity program support over the next farm bill. This is because the support levels are based on a moving 5-year average of historical prices and county yields and over the next 5 years, the ARC-Co support formula will use the recent set of low farm prices as a base.

Therefore, the concern of Arkansas producers is whether the reference price support in the PLC program will help them survive financially, should market prices continue to remain low over the next farm bill period. To examine this question, the estimated costs of production by commodity on a per unit basis for the representative Arkansas farms are compared. Table 6 provides a summary of the projected weighted average costs of production for the 2016-2018 and 2019-2023 periods. Reference prices of the PLC are then estimated as a percent of these cost estimates, indicating the degree of program support.

Table 6 also provides the current actual and effective reference price under the 2014 farm bill. Actual reference prices in the 2014 farm bill apply to only 85% of base acres enrolled in the program. For example, the $8.40/bu reference price for soybeans is effectively only $7.14/bu for all soybean base acre production. In addition, sequestration reduces this payment further by 6.8% of the actual reference price or by $0.49/bu. Therefore, the effective PLC support level for base program production is $6.65/bu compared to the legislated PLC reference price of $8.40/bu. In the same table below, Arkansas representative costs of production are estimated as a percent of the legislated actual and effective reference prices. Additional discounts on the effectiveness of the support level could also include the fact that payments are made on program base yields rather than actual yields. However, given the year-to-year variability of actual yields, this discount has not been included in the effective reference price estimate.

The results highlight that, except for peanuts, current actual or effective reference prices are not sufficient for any of the major Arkansas crops relative to estimated costs of production. For soybeans, an $8.40/bu reference price only covers 66% of the average per bu cost of soybeans for the 2019-2023 period. Given that the effective support is only $6.65/bu, then coverage is only 52%. The results are relatively better for rice and cotton, but similarly unfavorable for Arkansas corn as the estimates in Table 6 show.

Government Program Payment Limit Impacts on Arkansas Representative Farms. The Commodity Title of the farm bill establishes the payment limit of $125,000 for an individual and $250,000 for a married couple. Additional entities are eligible subject to rules of being "actively engaged in farming". In the analysis of Arkansas representative farms, the probability that a two-entity farming operation would be constrained by the $250,000 payment limit has been estimated (Fig. 1). To make these estimates, the FAPRI projected prices and county projected yields are used to estimate the farm operator's commodity payments. The Arkansas five representative farm operations have been simulated 500 times for each year from 2017 to 2023 using random draws of prices and yields to estimate the probability of payments exceeding the $250,000 payment limit. These random prices and yields are based on historical variation observed in the respective county where each representative farm is located. The commodity program payments as a percentage of total cash receipts for each representative farm (2017-2013) is located in Fig. 2.

Table 7 presents the results for each farm. The McGehee farm, with the highest percent of soybean production, is estimated to be adversely impacted by the $250,000 payment limit for the 2019 to 2023 crop years. There is also a high probability that given variation in prices and yields that this farm will be subject to payment limit levels at least 44% of the time out to 2023. The Hoxie and Stuttgart farms are also likely to be adversely impacted 56% to 66% of the time for the 2019-2023 crop years. For the Mississippi County farm, with the new seed cotton PLC program, payments limits will be met 100% of the time over the 2019-2023 period. The Wynne farm is not likely to face payment limits except in 2021 and 2022.

Table 7 also provides estimates of total cash receipts and net cash farm income. All farms except the Mississippi County farm experience at least one year when cash receipts, plus government commodity payments, are not sufficient to avoid losses in net cash farm income. Without the commodity program, Arkansas crop farms would experience significant financial stress.

Practical Applications

This study highlights the inadequacy of reference prices for key Arkansas crops, given the likely cost projections for each of the five crops. It also indicates that because of the size of Arkansas crop farms that they have a high probability of being limited in program payments by the payment limit rules in the current farm bill legislation. Low commodity prices and rising costs over the 2019-2023 time period suggests that the farm bill commodity program will continue to be important in sustaining the economic viability of Arkansas crop farms.

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Table 1. Stuttgart, Arkansas representative farm acreage and crop allocation.

Particulars	Soybean	Long-Grain Rice	Corn	Total
Planted Acres	1458.0	1458.0	324.0	3240.0
Base Acres	1296.0	1620.0	0.0	2916.0
Price Loss Coverage Payment Yield	47.2	65.3	0.0	
Percent Cropland Owned	20.0%	20.0%	20.0%	
Percent Cropland Cash-Rented	32.1%	32.1%	32.1%	
Percent Cropland Share-Rented	47.9%	47.9%	47.9%	
Net Percent Production[a]	90.4%	90.4%	90.4%	
Effective Base Acres	1171.8	1464.8	0.0	2636.6
Effective Planted Acres	1318.3	1318.3	293.0	2929.6

[a] NPP = (% cropland share rented * (1-% landlord's share in production)) + (% cropland owned) + (% cropland cash rented).

Table 2. Wynne, Arkansas representative farm acreage and crop allocation.

Particulars	Irrigated Soybean	Long-Grain Rice	Total
Planted Acres	1250.0	1250.0	2500.0
Base Acres	1250.0	1250.0	2500.0
Price Loss Coverage Payment Yield	36.4	66.3	
Percent Cropland Owned	50.0%	50.0%	
Percent Cropland Cash-Rented	25.0%	25.0%	
Percent Cropland Share-Rented	25.0%	25.0%	
Net Percent Production[a]	93.8%	93.8%	
Effective Base Acres	1171.9	1171.9	2343.8
Effective Planted Acres	1171.9	1171.9	2343.8

[a] NPP = (% cropland share rented * (1-% landlord's share in production)) + (% cropland owned) + (% cropland cash rented).

Table 3. McGehee, Arkansas representative farm acreage and crop allocation.

Particulars	Full-Season Soybeans	Long-Grain Rice	Corn	Total
Planted Acres	3900.0	650.0	1950.0	6500.0
Base Acres	3475.8	2263.8	617.4	6357.0
Price Loss Coverage Payment Yield	39.8	55.0	126.3	
Percent Cropland Owned	18.5%	18.5%	18.5%	
Percent Cropland Cash-Rented	20.4%	20.4%	20.4%	
Percent Cropland Share-Rented	61.2%	61.2%	61.2%	
Net Percent Production [a]	84.7%	84.7%	84.7%	
Effective Base Acres	2944.4	1917.7	523.0	5385.1
Effective Planted Acres	3303.8	550.6	1651.9	5506.3

[a] NPP = (% cropland share rented * (1-% landlord's share in production)) + (% cropland owned) + (% cropland cash rented).

Table 4. Mississippi County Arkansas representative farm acreage and crop allocation.

Particulars	Soybeans	Irrigated Cotton	Irrigated Cottonseed	Peanuts	Corn	Total
Planted Acres	1000.0	2500.0	2500.0	1000.0	500.0	5000.0
Base Acres	999.9	0.0	0.0	999.9	500.0	2499.8
Price Loss Coverage Payment Yield	21.0	0.0	0.0	1.4	112.0	
Percent Cropland Owned	20.0%	20.0%	20.0%	20.0%	20.0%	
Percent Cropland Cash-Rented	16.0%	16.0%	16.0%	16.0%	16.0%	
Percent Cropland Share-Rented	64.0%	64.0%	64.0%	64.0%	64.0%	
Net Percent Production [a]	84.0%	84.0%	84.0%	84.0%	84.0%	
Effective Base Acres	839.9	0.0	0.0	839.9	420.0	2099.8
Effective Planted Acres	840.0	2100.0	0.0	840.0	420.0	4200.0

[a] NPP = (% cropland share rented * (1-% landlord's share in production)) + (% cropland owned) + (% cropland cash rented).

Table 5. Hoxie Arkansas representative farm acreage and crop allocation.

Particulars	Irrigated Soybeans	Dry Land Soybeans	Medium-Grain Rice	Long-Grain Rice	Corn	Total
Planted Acres	1225.0	125.0	360.0	2040.0	250.0	4000.0
Base Acres	1225.0	125.0	360.0	2040.0	250.0	4000.0
Price Loss Coverage Payment Yield	37.0	37.0	67.5	67.5	101.9	
Percent Cropland Owned	25.0%	25.0%	25.0%	25.0%	25.0%	
Percent Cropland Cash-Rented	25.0%	25.0%	25.0%	25.0%	25.0%	
Percent Cropland Share-Rented	50.0%	50.0%	50.0%	50.0%	50.0%	
Net Percent Production [a]	87.5%	87.5%	87.5%	87.5%	87.5%	
Effective Base Acres	1071.9	109.4	315.0	1785.0	218.8	3500.0
Effective Planted Acres	1071.9	109.4	315.0	1785.0	218.8	3500.0

[a] NPP = (% cropland share rented * (1-% landlord's share in production)) + (% cropland owned) + (% cropland cash rented).

Table 6. Comparison of Price Loss Coverage reference prices to Arkansas crop cost of production estimates.

	Reference Price		2016 – 2018 Average			2019 – 2023 Average		
Crop	Actual	Effective	Cost Estimate	Ref % Cost	ERef % Cost	Cost Estimate	Ref % Cost	ERef % Cost
Soybeans $/bu	$8.40	$6.65	$11.69	72%	57%	$12.68	66%	52%
Rice $/cwt	$14.00	$11.09	$13.36	105%	83%	$15.33	91%	72%
Corn $/bu	$3.70	$2.93	$4.87	76%	60%	$5.16	72%	57%
Cotton $/lb	$0.367	$0.287	$0.364	101%	79%	$0.378	97%	76%
Peanuts $/ton	$535.00	$423.83	$242.50	221%	175%	$247.80	216%	171%

Table 7. Payments without limits compared to two-entity limit of $250,000 for Arkansas Representative Farms, total cash receipts and net cash farm income.

Farm	Program Payment	2017	2018	2019	2020	2021	2022	2023
McGehee	Payment w/o limit ($ 1000)	162.9	206.4	286.6	289.1	287.4	284.1	282.4
	Prob. reaching 250K limit	35%	44%	58%	57%	58%	57%	58%
	Total Cash Receipts ($ 1000)	4,156.8	4,464.1	4,600.8	4,700.0	4,736.2	4,789.3	4,855.1
	Net Cash Farm Income ($ 1000)	-15.9	328.4	356.4	206.4	38.2	-65.4	-141.2
Hoxie	Payment w/o limit ($ 1,000)	212.9	235.8	327.4	330.3	328.3	324.5	322.6
	Prob. reaching 250K limit	48%	51%	64%	66%	66%	66%	66%
	Total Cash Receipts ($ 1000)	2,421.1	2,503.1	2,431.6	2,447.9	2,458.9	2,479.4	2,496.2
	Net Cash Farm Income ($ 1000)	-57.0	62.6	-78.0	-225.1	-334.2	-417.4	-479.2
Mississippi County	Payment w/o limit ($ 1000)*	205.6	155.8	366.4	541.8	428.7	363.8	389.8
	Prob. reaching 250K limit	0%	0%	100%	100%	100%	100%	100%
	Total Cash Receipts ($ 1000)	3,828.8	3,915.8	4,096.1	4,171.6	4,224.8	4,289.8	4,341.5
	Net Cash Farm Income ($ 1000)	1121.7	1184.7	1304.6	1283.1	1256.8	1244.3	1222.9
Stuttgart	Payment w/o limit ($ 1000)	173.3	187.0	259.7	262.0	260.5	257.4	255.9
	Prob. reaching 250K limit	37%	43%	56%	57%	57%	59%	58%
	Total Cash Receipts ($ 1000)	2,297.0	2,332.8	2,317.3	2,335.0	2,342.5	2,352.9	2,367.4
	Net Cash Farm Income ($ 1000)	222.0	298.1	229.8	113.8	22.6	-53.9	-115.4
Wynne	Payment w/o limit ($ 1000)	122	163.1	143.4	107.7	268.4	268.4	67.7
	Prob. reaching 250K limit	25%	32%	26%	20%	57%	57%	14%
	Total Cash Receipts ($ 1000)	1,624.6	1,662.6	1,683.3	1,719.5	1,640.7	1,648.0	1,770.2
	Net Cash Farm Income ($ 1000)	205.1	265.9	236.6	174.0	18.8	-19.4	49.6

* Seed cotton payments calculated using 100% of generic base acres in Price Loss Coverage.

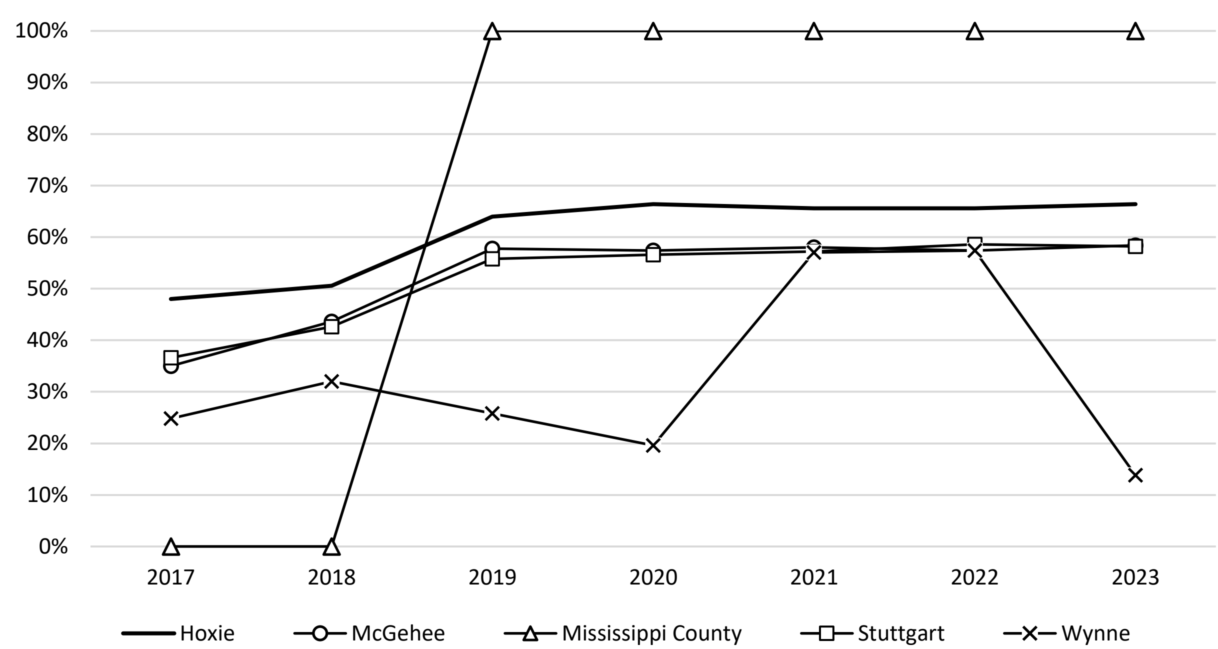

Fig. 1. Probability of Arkansas representative farms reaching the $250,000 commodity payment limit, 2017-2023.

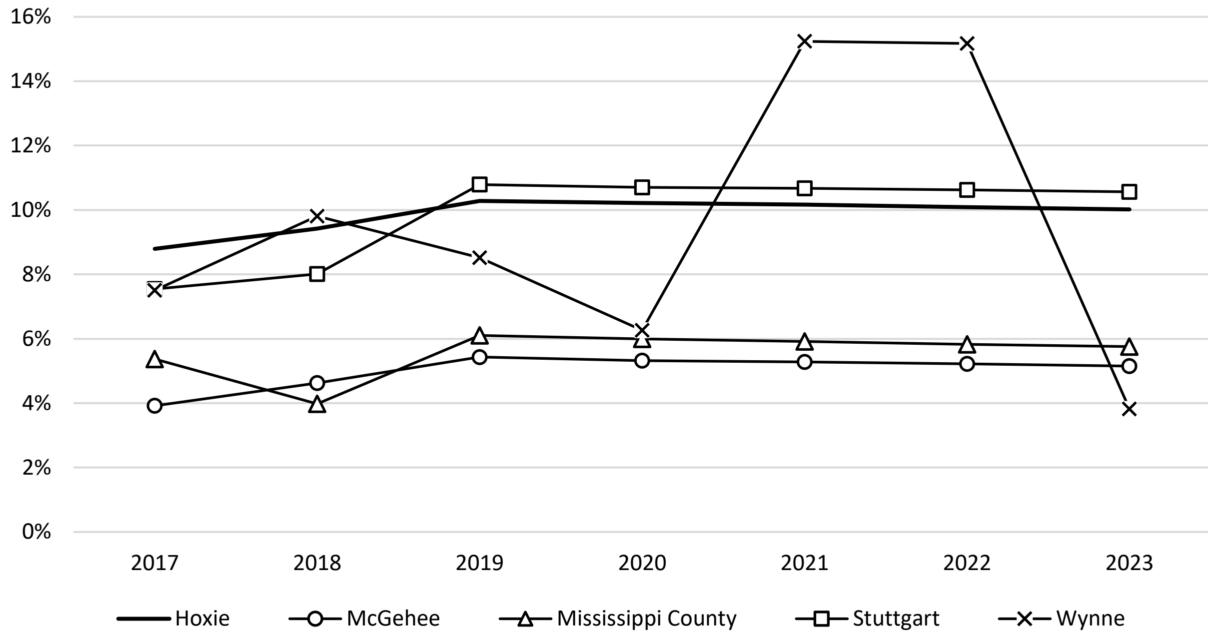

Fig. 2. Commodity program payments as a percentage of total cash receipts, Arkansas representative farms, 2017-2023.

Irrigation Termination Timing and Possible Interactions with Foliar Fungicide in Northeast Arkansas Soybeans

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Abstract

Irrigation termination timing and use of automatic foliar fungicide was evaluated in a 2017 replicated on-farm study conducted in a furrow-irrigated commercial soybean field with clay soils in Mississippi County, Arkansas. The 2 × 4 factorial experiment was arranged in a split-plot design and replicated three times. Final irrigation was applied at the R5, R6 or late R6.5 growth stages; there was also a rainfed check. Plots also were either untreated or sprayed with an automatic, preventative, foliar fungicide application at the R3 growth stage to protect yield from foliar disease-related losses. The 2017 season was characterized by higher than average rainfall during critical crop developmental stages. Soil moisture monitoring indicated that conservative thresholds to trigger irrigation were generally not exceeded in any treatment. All irrigated plots received at least two irrigations. Yields ranged from 69 to 72 bushels per acre, and highest mean yield was observed in the rainfed treatment. Significantly lower yields were associated with all irrigation timing treatments. No differences in foliar disease symptoms (e.g., frogeye leafspot) were observed. Fungicide applications on the disease-resistant cultivar had no impact on yield, and there was no interaction with irrigation practices. An integrated pest management (IPM) approach to plant disease management emphasizes use of disease resistance cultivars which can eliminate the need for costly, preventative chemical control. Use of soil moisture monitoring and appropriate field irrigation thresholds can help producers to avoid unnecessary irrigation and improve water management efficiency while maintaining high yields. Adoption of improved irrigation scheduling and recommended IPM tactics are expected to allow producers to increase profitability and contribute to a sustainable soybean production system.

Introduction

Irrigation scheduling, particularly the decision on *when to terminate irrigation* can be challenging for Arkansas soybean producers. Moisture availability should be managed in late season to avoid water deficits that limit seed size and diminish yield potential. If the irrigation season is prolonged beyond what the crop requires, harvest may be delayed. Extended irrigation may exacerbate insect pest risks and favor disease development. Unneeded irrigation applications are an inefficient use of precious water resources, and late-season pumping typically is the most expensive of the summer due to increasing depth to groundwater after a long pumping season. Irrigation termination timing recommendations for Arkansas soybean are based on predominant soil texture as well as plant growth stage (Henry et al., 2014; Tacker and Vories, 1998). Current University of Arkansas System Division of Agriculture's Cooperative Extension Service recommendations suggest that irrigation should be terminated at R6.5 if there is adequate soil moisture. On many northeast Arkansas soybean farms, preventative foliar fungicide applications are routinely made during flowering for protection from frogeye leaf spot (*Cercospora sojina*). If not managed properly, severe yield losses can occur on susceptible cultivars when conditions favor disease development (Faske, 2017). Use of costly fungicides may be unnecessary if disease resistant cultivars are used. This 2017 field trial was conducted to validate current irrigation termination recommendations including possible interactions with fungicidal protectants effective against soybean foliar diseases including frogeye leaf spot.

Procedures

The research site was a commercial farm located near Victoria, Ark., in an 80 acre field (35°45'32.1"N 90°06'39.4"W) with soils mapped as a Sharkey-Steel complex and Sharkey silty clay (SSURGO, 2015). The experiment was arranged in a split-plot design with fungicide treatment considered the main plot and irrigation termination considered the sub-plots (Fig. 1). Sub-plots extended the length of the field (1250 ft.), and plot width was 13 rows wide (38-in. row spacing). There were 6 row buffers separating fungicide main plots. Irrigation termination timing details are summarized in Table 1. Irrigation was applied using 18-in. × 10-mm poly irrigation tubing and a computerized hole selection program (PHAUCET) was used to improve uniformity of irrigation sets. Cultivar Armor™ 47D17 soybeans were planted in twin rows

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on raised beds on 18 May 2017. According to Armor Seed Company literature, this cultivar is considered resistant to frogeye leaf spot. On 13 July, when soybeans were at the R3 stage, the cooperating producer applied Aproach Prima© 2.34 SC (6.8 oz/ac) (picoxystrobin + cyproconazole) (FRAC Code 11+3) in appropriate main plots. All standard field operations were similar across the field with only irrigation and fungicide applications altered among treatments. Soil moisture measurements were monitored using Watermark sensors (Irrometer; Riverside, Calif.) installed at two depths (6-in. and 12-in.) and positioned in the top of the bed at two sites near the center of each irrigation plot. Plots were harvested on 4 Oct. Yield evaluations were made using yield monitor measurements taken from a harvest swath in the center 9 rows of each plot running the length of the field. Data were analyzed using PROC MIXED (SAS Institute; Cary, N.C.).

Results and Discussion

The 2017 season was characterized by above average rainfall in July and August with lower than average rainfall amounts in September and early October (Table 2). At times, irrigation timings were confounded by rain events. Watermark sensor data showed that soil moisture levels in irrigated plots did not exceed -50 kPa, and in only one period in the season did sensors in the rainfed treatment (no irrigations) exceed -75 kPa (Fig. 2). Recommended irrigation triggers in silt loam and clay soils vary from 50 up to 75 kPa (Tacker and Vories, 1998; Krutz and Roach, 2016).

Yields ranged from 69 to 72 bushels per acre (Fig. 3). There were no differences among irrigation termination timing treatments. Highest yields were observed in the rainfed treatment (P = 0.03). Yields were similar for the fungicide sprayed and unsprayed treatments (P = 0.77), and there were no significant irrigation × fungicide interactions (P = 0.80). It is unknown why irrigation significantly reduced yield. There were no observed differences in insect pest densities or foliar disease symptoms across treatments during the production season.

Practical Applications

Cues for timing irrigation can come from monitoring plants, soil, weather, or combinations of all three. Soil moisture measurements and use of irrigation field thresholds can signal that irrigation can be postponed or averted in the event of timely precipitation. Over-irrigation can result in yield penalties. Integrated Pest Management (IPM) practices include use of cultural control methods such as selection of resistant cultivars and scouting by qualified crop advisors. An IPM approach will reduce the need for chemical control tactics including preventative applications of costly crop protectants. Adoption of improved irrigation scheduling and recommended IPM techniques will have a positive effect on production efficiency and farm profitability and contribute to a sustainable soybean production system.

Acknowledgements

The authors extend special thanks to Jeff Lammers for cooperation and support for on-farm research. Funding for the project was provided by the Arkansas Soybean Promotion Board. Additional support was provided by the University of Arkansas System Division of Agriculture, Arkansas State University, the USDA-ARS DWMRU, and the USDA National Institute of Food and Agriculture (project ARK02355).

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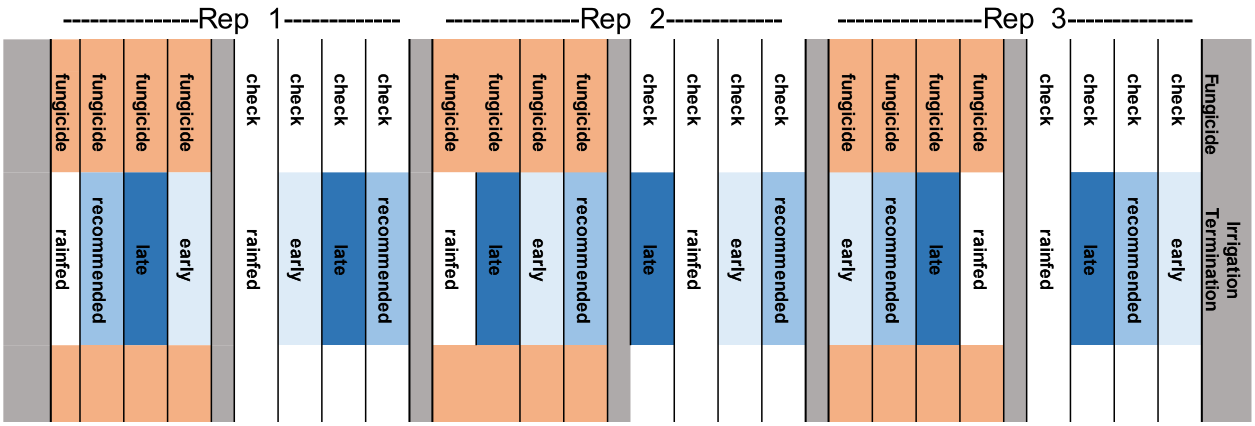

Fig. 1. Field plan for the 2017 irrigation termination × fungicide trial in Mississippi County, Arkansas; the experiment was a 2 × 4 factorial arranged in a split-plot design with 3 replications.

Table 1. Timing for irrigation termination timing and fungicide application including plant growth stage, dates, and number of days after planting–2017, Victoria, Ark.

		Treatment timing[a]		
Treatment		**Growth stage**	**Date**	**Days after planting**
Irrigation Termination	Rainfed (check)	-	-	-
	Early termination	R5	20 July	88
	Recommended	R6	24 Aug	110
	Late termination	R6.8	20 Sept	137
Fungicide Application	No application (check)	-	-	-
	Fungicide	R3	13 July	68

[a]All irrigated treatment plots received irrigation 75 and 88 days after planting (DAP).

Table 2. Monthly precipitation (inches) measured at the study site for the 2017 season compared with 30-year average for the county, Victoria, Ark.

Month	**30-year Average**	**2017 Rainfall**	**Departure**
	----------------------------------inches----------------------------------		
May	5.46	5.59	0.13
June	3.92	2.08	-1.84
July	4.04	5.67	1.63
August	2.86	6.9	4.04
September	3.37	1.28	-2.09
October	3.9	2.98	-0.92
Total	23.55	24.5	0.95

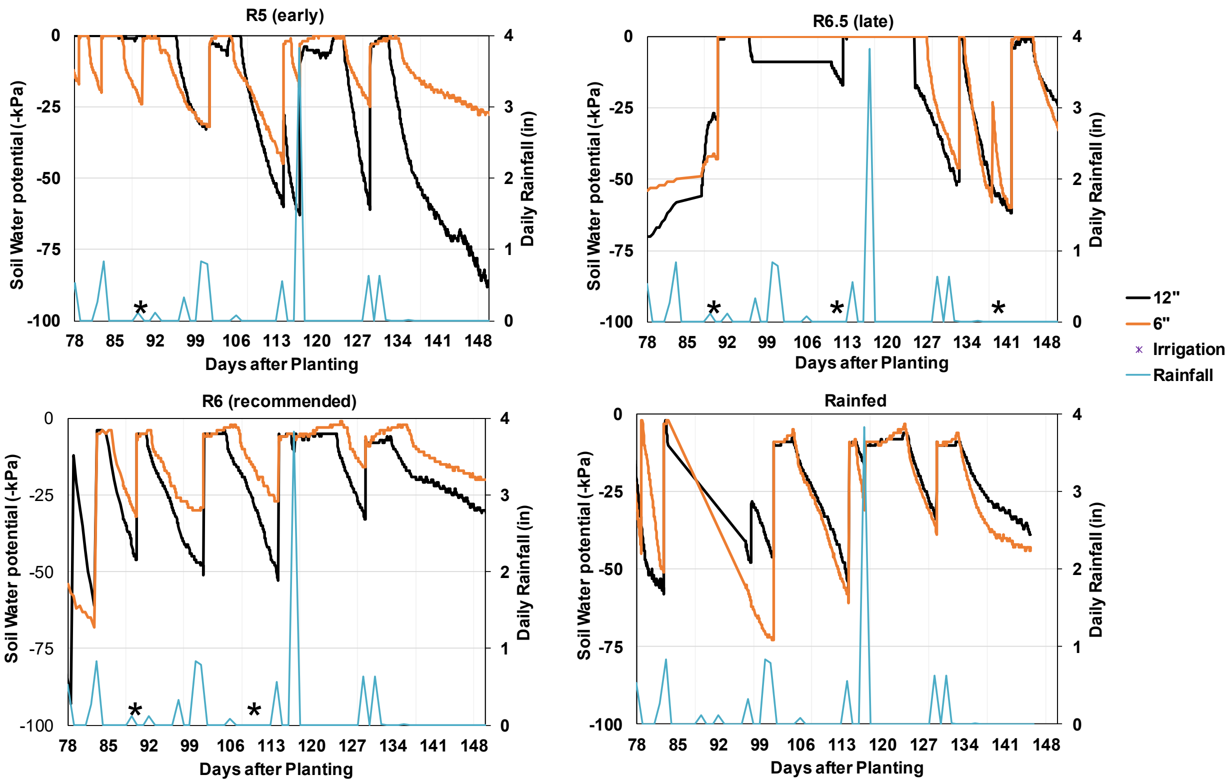

Fig. 2. Mean soil water potential (kPa) at 6- and 12-inch depths in clay soil with rainfall and irrigation events plotted with days after planting for four irrigation treatments in the 2017 soybean irrigation initiation trial, Victoria, Ark.

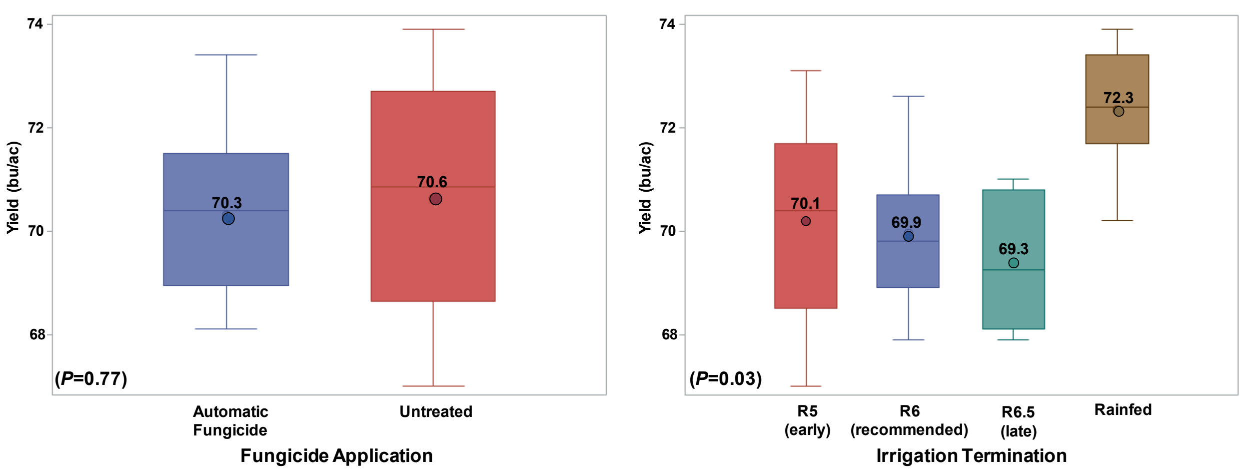

Fig. 3. Soybean yield (bu/ac) for main plot fungicide treatment (left) and for sub-plot irrigation termination treatment determined from yield monitor data, 2017–Victoria, Ark. Boxes represent 50% quartile; circles within the box depict means, and the line is the median value. Mean yield values also are shown. There were no significant interactions (*P* = 0.80).

Long-Term Residue Management and Irrigation Practice Effects on Aggregate-Derived Particulate Organic Matter Fractions in a Wheat-Soybean, Double-Crop System

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Abstract

Conventional agricultural management practices, such as repeated annual tillage and crop residue burning, can lead to reductions in soil carbon (C) storage and degrade soil health. Through the use of conservation tillage and alternative residue management practices, the soil C pool can increase. The objective of this field study was to evaluate the effects of long-term agricultural management practices (i.e., residue level, residue burning, irrigation, and tillage) on soil particulate organic matter (POM) fractions and their associate C and nitrogen (N) concentrations in a wheat (*Triticum aestivum*)-soybean (*Glycine max* L. [Merr.]), double-crop production system on a silt-loam-textured, loess soil following 14 complete cropping cycles in eastern Arkansas. Averaged over irrigation and tillage, the fine POM C concentration in the burn-low- (2.59 g/kg) was 1.9 times greater (P = 0.04) than in the burn-high-residue treatment combination (1.35 g/kg), while the fine POM C concentration in the no-burn-high- and no-burn-low-residue combination were intermediate and did not differ (2.56 and 2.43 g/kg, respectively). The fine POM N concentration, averaged over irrigation and tillage treatments, was 1.9 times greater (P = 0.02) in the burn-low- (0.21 g/kg) than the burn-high-residue combination (0.11 g/kg), while the fine POM N concentration in the no-burn-high- and no-burn-low-residue combinations did not differ (0.21 and 0.23 g/kg; respectively). Sustainable management practices in a wheat-soybean, double-crop production system in eastern Arkansas, such as no-tillage (NT) and non-burning of crop residues, compared to the traditional practices of conventional tillage (CT) following residue burning, provide alternative management practices that can potentially reduce the dependency on external inputs, including irrigation and nutrient inputs.

Introduction

In the Lower Mississippi River Delta (LMRD) region of eastern Arkansas, groundwater aquifer levels continue to decline from extensive agricultural irrigation (Scott et al., 1998). Agricultural withdrawals, coupled with increased volatility and unpredictability of weather patterns due to climate change result in a need for increasing resiliency of agricultural soils in addition to the soil's use as a potential carbon (C) sink (IPCC, 2013). Soil organic matter (SOM), some of which is at least partially microbially processed organic residues within soils that is resistant to further microbial degradation, contains the largest terrestrial C reserve in the form of soil organic carbon (SOC), (Follet, 2001; Lal, 2000).

Conventional agricultural management practices, such as repeated annual tillage and crop residue burning, can lead to reductions in soil C storage and degrade soil health, which is the capacity of a soil to sustain or promote plant and animal health and productivity, while maintaining or enhancing water and air quality (Doran, 2001; Franzluebbers and Doraiswamy, 2007). Approximately half of the SOC pool can be depleted compared to undisturbed ecosystems (i.e., forest and grasslands) following conversion to cultivated agriculture within 10 years, largely due to conventional tillage (Lal and Bruce, 1999). Implementing sustainable agricultural management practices and technologies that increase food production, while improving environmental conditions, can provide a semi-permanent C sink by increasing SOC storage (Pretty, 2008). Through the use of conservation tillage and alternative residue management practices, the SOC pool can increase substantially. Practices that reduce microbial activity and SOM decomposition, decrease soil disturbances, and increase plant productivity, such as fertilization, cover cropping, and irrigation, are attributed to increases in SOM and subsequent SOC fractions.

In a process described by Six et al. (1999), upon entry into the soil, fresh residues partially decompose forming particulate organic matter (POM), thus forming nucleation centers for aggregation and microbial activity (Puget et al., 1995). This microbial activity results in the binding of fresh residues and induces macro-aggregate (>250 µm or >0.01 in.) formation, which subsequently break down to form micro-aggregates (53–250 µm or 0.002–0.01 in.; Six et al., 2004). The non-aggregated mineral fraction consists of silt- and clay-free primary particles (<53 µm or <0.002 in.). Macro- and micro-aggregates reduce the degradation of labile C by physically protecting the coarse- and fine-POM, respectively. The aggregate protective capacity (PC; the protection of SOC against biodegradation) generally increases with increases in SOM and clay and reductions in tillage or other soil disturbances (Balesdent et al., 2000). Several mechanisms are responsible for macro-aggregate PC, including sorption of SOM to solid surfaces, sequestration into small pores, control of microbial turnover by predators, and O_2 limitation (Balesdent et al., 2000). Quantifying C derived from within and between aggregate fractions can further support the understanding of POM-associated C accumulation by increasing PC.

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The objective of this field study was to assess and compare the effects of long-term agricultural management practices (i.e., residue level, residue burning, irrigation, and tillage) on soil aggregate and POM aggregate-derived C and N concentrations (i.e., macro-aggregate, micro-aggregate, coarse- and fine-POM C and N concentrations) in a wheat *(Triticum aestivum*)-soybean (*Glycine max* L. [Merr.]), double-crop production system on a silt-loam-textured, loess soil following 14 complete cropping cycles in eastern Arkansas. Compared to the currently common practices of residue burning and conventional tillage (CT), the effects of non-residue burning and NT are hypothesized to increase soil micro-aggregate POM C and N concentrations.

Procedures

A wheat-soybean, double-crop system consisting of 48, 10-ft wide by 20-ft long plots including three replications of 16 differing residue and water management combinations at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Branch Experiment Station near Marianna, Ark. has been established since 2002. The differing management practices include wheat residue burn and no burn, CT and no-tillage (NT), high- and low-wheat residue level, and irrigated and dryland soybean production. Further details of annual plot management are provided in Desrochers (2017). On 15 Sept. 2015, 12 to 15, 0.8-in.-diameter soil cores were collected at random from the top 4 in. (10 cm) and combined for one sample per plot to assess long-term management practice effects on POM fractions and their associated C and N concentrations according to procedures described by Six et al. (1999; Fig. 1).

After air-drying for several weeks, soil samples were hand-crushed to pass through a 0.3-in. (8-mm) sieve, then two sub-samples of approximately 3.35 oz (95 g) per plot of air-dried soil were separately wet-sieved using a soil-slaking procedure to derive macro- (>250 µm or >0.01 in.), micro-aggregate (>53 to <250 µm or >0.002 to <0.01 in.), and silt-clay (<53 µm or <0.002 in.) fractions (Elliott, 1986; Cambardella and Elliott, 1993; Six et al., 1998; Fig. 1). The fractionation procedure is further explained in Desrochers (2017).

To obtain total POM (i.e., POM within and around aggregate fractions), two, approximately 0.18-oz (5-g) sub-samples of the macro- (>250 µm or >0.01 in.) and micro-aggregate (>53 µm or >0.002 in.) fractions were placed in 1.8-oz (50-mL), glass beakers and oven-dried overnight at 221 ˚F (105 ˚C) in a forced-air oven to obtain the coarse and fine total POM, respectively. The next morning, both respective sub-samples were removed from the oven, cooled in a desiccator, weighed, and added to 3.5-oz (100-mL) cylindrical glass tubes filled with 1.1 oz (30 mL) of sodium hexametaphosphate solution [5 g/L $(NaPO_3)_6$] and shaken on a reciprocal shaker for 18 hours or overnight to accomplish full dispersion. Dispersed samples were then poured over a 0.002-in. (53-µm) sieve in a plastic basin, rinsed thoroughly until th.e water coming through the sieve was clear, then the sand and total POM was lightly washed into a preweighed, 1.8-oz (50-mL) glass beaker and oven-dried overnight at 221 ˚F (105 ˚C). After 24 hours, the intra-aggregate sub-samples within the 1.8-oz (50-mL) beakers were cooled in a desiccator, weighed, and stored in 0.7-oz (20-mL) glass scintillation vials for subsequent chemical analyses. The difference in the initial 0.18-oz (5-g) sub-sample mass and total POM mass constituted the silt and clay fraction. The sand fraction was assumed to equal the mass of the total POM, and C or N concentrations per aggregate were adjusted to a sand-free basis using the following formula (Six et al., 1998):

$$\text{Sand-free (C or N)}_{\text{fraction}} = \frac{\text{(C or N)}_{\text{fraction}}}{1 - \text{(sand proportion)}_{\text{fraction}}}$$

Bulk soil, macro- and micro-aggregate and coarse- and fine-POM sub-samples were homogenized by grinding/mixing for 20 seconds with a metal ball using a Wig-L Bug® (Model MSD, DENTSPLY, York, Pa.). Soil-fraction sub-samples were weighed in small tin capsules for C and N concentration analyses using an elemental analyzer (Model NC2500, Carlo Erba, Milan, Italy).

Due to confounding logistical constraints, the irrigation treatment block added in 2005 directly corresponds to the residue-burn treatment block, making both treatments unable to be simultaneously statistically analyzed. As a result, two separate three-factor analyses of variance (ANOVAs) were conducted using the MIXED type-three, least-squared procedure in SAS v. 9.4 (SAS Institute, Inc., Cary, N.C.) to evaluate the effects of tillage, burning, residue level, and their interactions as well as tillage, irrigation, residue level, and their interactions on bulk-soil C and N concentrations, aggregate-separated C and N concentrations (i.e., silt-clay, macro- and micro-aggregate), coarse- and fine-POM C and N concentrations, and coarse- and fine-POM C:N ratio. Means were separated by least significant difference at the 0.05 level.

Results and Discussion

Several main effects and treatment interactions occurred for the aggregate- and POM-separated soil fractions; however bulk-soil C was only affected by irrigation, while bulk-soil N did not differ among treatments and averaged 1.15 g/kg. Averaged over tillage, residue-level, and burn, bulk-soil C concentration in the irrigated treatment was 1.21 times greater ($P = 0.02$) than in the non-irrigated treatment (13.2 and 10.9 g/kg, respectively).

Within the sand-free, macro-aggregate fraction, averaged over irrigation, burn, and residue-level treatments, C concentration was 9.9% greater ($P = 0.05$; Table 1) under NT (17.1 g/kg) than under CT (15.6 g/kg), likely due to a reduction in annual soil disturbance from tillage disrupting macro-aggregates. Additionally, Andruschkewitsch et al.

(2013) observed greater macro-aggregate C concentration differences in NT (178 lb/ac) compared to CT (116 lb/ac) in the top 2 in. (5 cm) of a silt-loam soil. Comparatively, Six et al. (1998) did not observe macro-aggregate C concentration differences between NT and CT in the top 2 in. (5 cm) of a Duroc silt loam (Pachic Haplustoll) in Sidney, Nebraska following 26 years of consistent management. In contrast, the C concentration of the sand-free micro-aggregate fraction was unaffected by any field treatment in this study, though Six et al. (1998) observed greater NT micro-aggregate C concentration compared to CT.

In both the macro- and micro-aggregate fractions, several field treatments significantly affected coarse-and fine-POM C and N concentrations in the top 4 in. (10 cm). Averaged over irrigation and tillage, the fine-POM C concentration in the burn-low- (2.59 g/kg) was 1.9 times greater ($P = 0.04$; Table 1) than in the burn-high-residue treatment combination (1.35 g/kg), while the fine-POM C concentration in the no-burn-high- and no-burn-low-residue combination were intermediate and did not differ (2.56 and 2.43 g/kg, respectively; Fig. 2). The burn-high-residue combination likely had a lower fine-POM C concentration from the cumulative effect of nearly 14 years of consistent management achieving a more thorough burn due to greater aboveground biomass and ultimately reducing the amount of potential crop residue and organic material returned to the soil. Additionally, the fine-POM N concentration, averaged over irrigation and tillage treatments, was 1.9 times greater ($P = 0.02$; Table 1) in the burn-low- (0.21 g/kg) than the burn-high-residue combination (0.11 g/kg), while the fine-POM N concentration in the no-burn-high- and no-burn-low-residue combinations did not differ (0.21 and 0.23 g/kg; respectively; Fig. 2). The burn-high-residue combination likely increased fine POM N concentration by stimulating greater SOM turnover and N mineralization after burning removed nearly all aboveground plant material on an annual basis. In comparison, coarse-POM C and N concentrations within the burn-residue-level combination did not differ and averaged 6.94 and 0.51 g/kg, respectively (Fig. 2).

When calculated using C and N concentrations, fine-POM C:N ratios in the top 4 in. (10 cm) differed among field treatments, while the bulk soil, macro- and micro-aggregate, and coarse-POM fraction C:N ratios were unaffected by field treatments. Andruschkewitsch et al. (2013) also did not observe a macro- and micro-aggregate difference in C:N ratio in the top 2 in. (5 cm). Averaged over tillage, burn, and residue-level treatments, the fine-POM C:N ratio was 16% ($P < 0.01$; Table 1) greater under non-irrigated (C:N ratio = 13.7) than irrigated soybean production (C:N ratio = 11.9), likely the result of greater soil moisture increasing microbial decomposition of SOM and loss of C through respiration.

Practical Applications

Greater overall POM C and N concentrations, and subsequent macro- and micro-aggregate C and N concentrations, can lead to improved soil fertility and soil C storage capacity, thus likely benefitting crop production and providing a C sink to mitigate climate change. Additionally, an increase in POM C and N concentration will increase soil health and, therefore, increase the natural resiliency of soils to sustain crop yields in the LMRD region of eastern Arkansas. Sustainable management practices in a wheat-soybean, double-crop production system in eastern Arkansas, such as NT and non-burning of crop residues, compared to the traditional practices of CT following residue burning, provide alternative management practices that can potentially reduce the dependency on external inputs, including irrigation and nutrient inputs.

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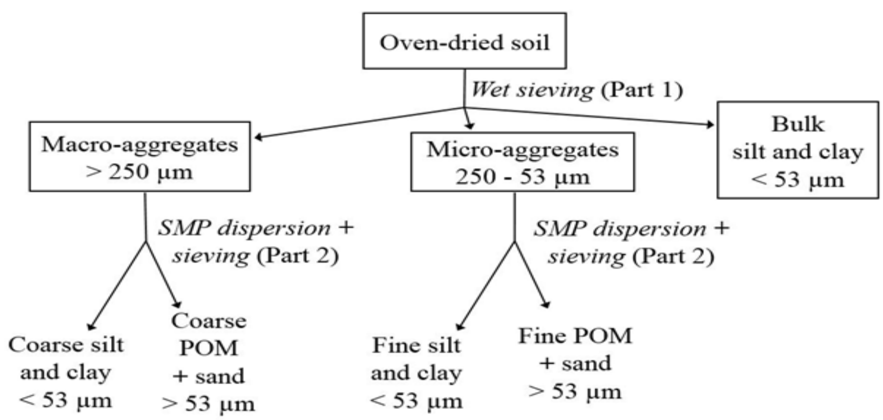

Fig. 1. Flow chart of the aggregate fractionation (Part 1) procedure to obtain macro-aggregates (> 0.01 in. or > 250 µm), micro-aggregates (> 0.002 to < 0.01 in. or > 53 to < 250 µm), and silt and clay fractions (< 0.002 in. or < 53 µm) and particulate organic matter (POM) separation (Part 2) procedure to obtain coarse- and fine-POM.

Table 1. Analysis of variance (ANOVA) summary of the effects of tillage, residue level, burning, irrigation, and their interactions on macro- and micro-aggregate, coarse- and fine-particulate organic matter (POM) carbon (C) and nitrogen (N) concentrations (g/kg sand-free aggregate) and their C:N ratios in the top 4 in. (10 cm) following more than 13 years of consistent management in a wheat-soybean, double-crop production system at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station near Marianna, Ark. on a silt-loam soil. Significant ($P < 0.05$) effects are bolded.

Source of variation	Macro- C	Macro- N	Macro- C:N	Micro- C	Micro-N	Micro-C:N	Coarse-POM C	Coarse-POM N	Coarse-POM C:N	Fine-POM C	Fine-POM N	Fine-POM C:N
						P						
Tillage (T)[a]	**0.05**	0.13	0.92	0.12	0.48	0.12	0.19	0.12	0.77	0.35	0.34	0.62
Residue level (RL)	0.57	0.59	0.72	0.38	0.64	0.07	0.94	0.61	0.22	0.03	0.07	0.37
Burn (B)	0.31	0.36	0.72	0.68	0.47	0.22	0.83	0.63	0.29	0.63	0.60	0.43
T × RL	0.75	0.27	0.88	0.71	0.29	0.34	0.58	0.95	0.56	0.91	0.76	0.33
T × B	0.49	0.65	0.13	0.92	0.73	0.55	0.14	0.30	0.16	0.96	0.45	0.09
B × RL	0.06	0.42	0.06	0.68	0.28	0.74	0.35	0.75	0.14	**0.04**	**0.02**	0.75
T × B × RL	0.40	0.47	0.89	0.86	0.92	0.56	0.79	0.42	0.22	0.52	0.31	0.34
Tillage[†]	0.13	0.13	0.75	0.12	0.48	0.12	0.32	0.23	0.75	0.35	0.34	0.63
Residue level	0.63	0.45	0.24	0.26	0.50	0.21	0.98	0.67	0.24	0.02	0.01	0.30
Irrigation (I)	0.44	0.43	0.60	0.22	0.41	0.59	0.09	0.19	0.60	0.31	0.28	**< 0.01**
T × RL	0.85	0.63	0.50	0.76	0.40	0.18	0.75	0.98	0.50	0.87	0.72	0.30
T × I	0.91	0.62	0.37	0.87	0.39	0.37	0.85	0.65	0.37	0.20	0.19	0.32
I × RL	0.09	0.19	0.19	0.08	0.10	0.32	0.13	**< 0.01**	0.19	0.72	0.82	0.74
T × I × RL	0.51	0.82	0.64	0.72	0.61	0.21	0.66	0.69	0.64	0.55	0.77	0.26

[a] Two sets of three-factor ANOVAs were conducted due to the similar blocking structure for the burn and irrigation treatments.

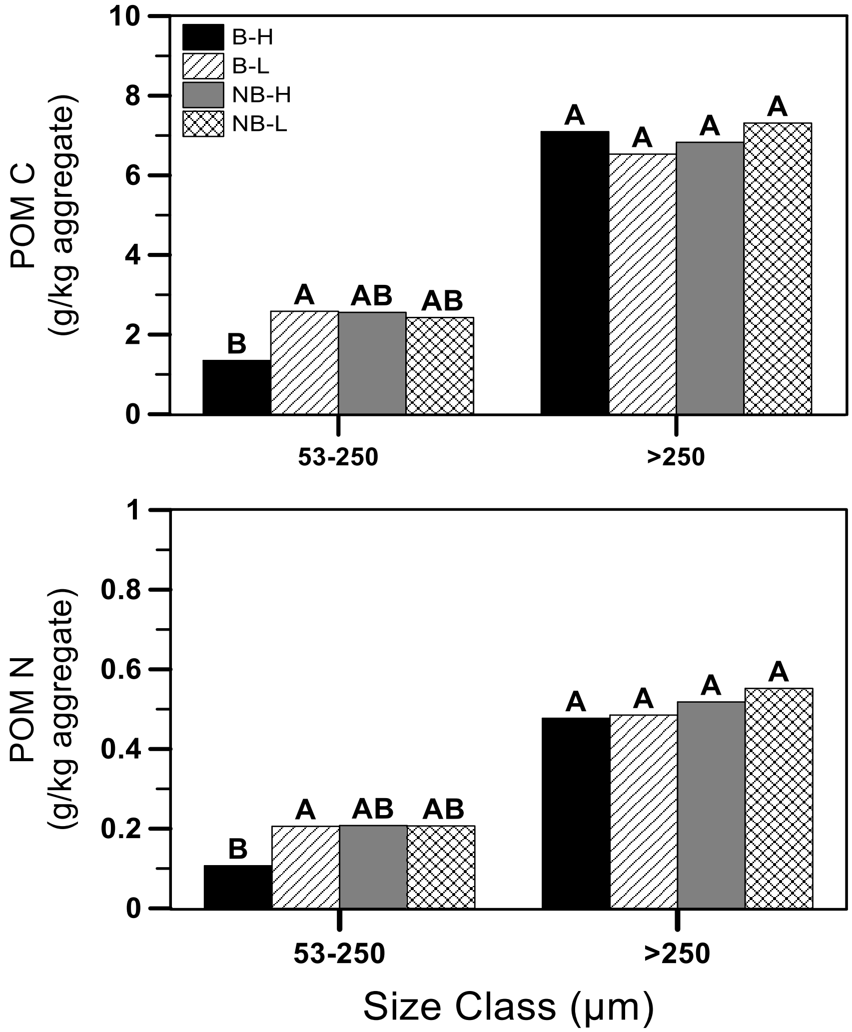

Fig. 2. Burn [burn (B) and no burn (NB)]-residue-level [high (H) and low (L)] treatment effects on particulate organic matter (POM) C and N concentration among aggregate-size classes (0.002-0.01 in. or 53-250 µm and > 0.01 in. or > 250 µm) in the top 4 in. (10 cm) of soil in September 2015 following more than 13 years of consistent management in a wheat-soybean, double-crop system near Marianna, Ark. Different letters atop bars within a size class within a panel denote significant differences (*P* < 0.05) between treatment combinations.

Evaluation of a Rapid, In-Field Method for Assessing Soybean Potassium Nutritional Status

N.A. Slaton[1], D.A. Sites[1], D.D. Cox[1], T. Richmond[1], J. Hardke[2], T.L. Roberts[1], and J. Hedge[3]

Abstract

Assessing plant potassium (K) sufficiency using plant sap may allow growers to examine crop K needs in the field rather than having to use traditional plant analysis to diagnose or monitor plant K sufficiency. The objectives of this experiment were to evaluate weekly petiole sap analysis as a tool for monitoring soybean [*Glycine max*. (L.) Merr.] K nutrition as compared to traditional tissue analysis. Leaf and petiole tissue K concentrations were compared to petiole sap-K concentrations for samples collected throughout the soybean reproductive growth phase from different K fertilizer rates in four trials. The tissue K concentrations from soybean leaves, petioles, and sap collected showed similarities as each decreased linearly across time; tissue and sap-K concentrations were linearly related with one another, and all methods measured increased K concentrations as K fertilizer rate increased. Sap-K concentration as measured on a handheld device appears to be a promising and rapid method that can be used in the field to monitor soybean nutrition.

Introduction

Plant tissue analysis in production agriculture has historically been used to diagnose nutrient-related maladies or eliminate nutrients as a possible cause after plants express symptoms. The now defunct (in Arkansas) cotton (*Gossypium hirsuturm* L.) petiole monitoring program was one of the few examples of a weekly tissue analysis program to monitor a crop for the nutritional status of selected nutrients (NO_3-N, P, K, and S; Sabbe and Zelinski, 1990). Traditional plant tissue analysis methods usually require at least 24 hours for sample preparation, analysis and result reporting with more time needed if samples must be mailed. In-field nutrient assessments are an alternative to traditional plant analysis but these rapid tests have limited application since research has been conducted primarily in vegetable crop production systems (Rosen et al., 1996; Hochmuth, 2015).

The rapid, in-field methods require that sap be extracted from plant tissue, usually petioles. After extraction, the sap is placed on a small handheld instrument, with the first instrument used for this purpose known as the 'Cardy meter'. The original Cardy meter is no longer available but Horiba Scientific (Kyoto, Japan) has developed a series of ion-specific, handheld instruments including one for potassium (K). One limitation for the use of in-field sap analysis as a crop nutrition-monitoring tool is that not all crops are well-suited for sap extraction. The objectives of this experiment were to evaluate weekly petiole sap analysis as a tool for monitoring soybean [*Glycine max.* (L.) Merr.] K nutrition and to compare petiole sap-K, petiole-K, and trifoliolate leaf-K concentrations during the growing season.

Procedures

Soybean grown in two long-term K rate trials and two K application timing trials were used to achieve the objectives of this experiment. The long-term trials included a 16-year trial at the University of Arkansas System Division of Agriculture's Pine Tree Research Station near Colt, Ark. (PTRS-LTK, Calhoun series) and a 10-year trial at the Rice Research and Extension Center near Stuttgart, Ark. (RREC-LTK, Dewitt series), which each include annual K rates of 0 to 160 lb K_2O/acre and are cropped to a rice-soybean rotation. The RREC-LTK trial was drill seeded (7.5-inch row spacing) into a no-till seedbed on 17 May with Armor 47-R13 soybean. The PTRS-LTK was drill seeded (15-inch spacing) into a no-till seedbed on 11 May with Pioneer 49T09 soybean. The two K timing trials were both located at the PTRS in fields that will be referred to as I-10 (Calloway series, Pioneer 47T36R) and F3 (Calhoun series, Armor 47-R70). Only two treatments in each trial were used for the objectives of this report and included preplant applications of 0 and 180 lb K_2O/acre. A summary of soil chemical properties including pH (1:2 soil-water mixture) and selected Mehlich-3 extractable nutrients before fertilizer treatment application is listed in Table 1. Selected data from these four trials will be used in this report.

No yield data from these trials is reported here since we were interested only in examining the trends in sap-K concentration among the different levels of K nutrition and comparing sap-K concentration (mg K/L) as determined with the Horiba B-731 LAQUAtwin Compact K Ion Meter with leaf-K and petiole-K concentrations determined via traditional analytical methods.

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Tissue samples consisting of two sets of petioles and trifoliolate leaves were collected on five or six different weeks from each trial (Table 2). The first set of tissue was digested with concentrated HNO_3 and 30% H_2O_2, and analyzed for K by inductively coupled plasma spectroscopy. The second set of tissue was used for sap extraction from petioles following the removal of trifoliolate leaves. The petioles were cut into 0.5-inch long pieces, placed in a handheld garlic press to extract the sap into a 3-mL plastic vial, and the vials were frozen until the analysis was conducted in the lab. This procedure generally extracted 0.50 to 0.75 mL sap.

The replicate K concentration data (n = 54) from petiole sap, petiole analysis, and leaf analysis from PTRS-LTK were regressed against the number of days after planting (DAP) using a model that initially included linear and quadratic terms of DAP which were allowed to depend on fertilizer-K rate. The relationship was refined by sequentially removing the most complex non-significant ($P > 0.15$) model terms and running the new model until a final model was reached. The relationships among the three K concentrations (petiole sap, petiole, and leaf) were determined using linear and quadratic models using data from all four trials (n = 81 or 96) that was available at the time this report was prepared.

Results and Discussion

The tissue K concentrations from soybean leaves, petioles, and sap collected from the PTRS-LTK trial showed some similarities as each decreased linearly across time (Figs. 1–3). Petiole sap-K (Fig. 1) and petiole-K (Fig. 2) concentrations each decreased at a uniform rate across time and depended on K fertilizer rate. Leaf-K concentration (Fig. 3) also decreased linearly across time but both the intercepts and slopes depended on K application rate. The R^2 for the three relationships was greatest for petiole-K (R^2 = 0.89, CV = 14.2%), intermediate for leaf-K (R^2 = 0.74, CV = 15.8%), and lowest for petiole sap-K (R^2 = 0.60, CV = 30.8%). The results indicate that sap-K is the most variable of the three measurements, which is not surprising since this is the first time we have extracted sap from tissue. The sap extraction process yielded different volumes of sap among sample times and may be related to soil moisture and plant hydration differences and the fact that the size of petioles changes during the season. A more efficient tool for extracting sap may improve the relationship and increase the speed and ease of sap extraction from petioles.

Data from all sample times and all four K trials were used to evaluate the relationships among sap-K, trifoliolate leaf-K, and petiole-K concentrations (not shown). The relationship between trifoliolate leaf-K and petiole-K concentrations was the strongest with an R^2 value of 0.79 and described by a linear relationship of petiole-K% = $2.45x - 0.68$ where x is % K in the trifoliolate leaves. Petiole-K concentration was approximately two times greater than the K concentration in the upper leaves. Predictions were least accurate when K concentrations were very low, such as late (R5.5 stage) in the growing season. Petiole-K concentration (R^2 = 0.45; mg sap-K L^{-1} = $0.067x + 0.020$ where x is % petiole-K) was a slightly better predictor of sap-K concentration than trifoliolate leaf-K concentration (R^2 = 0.42; mg sap-K L^{-1} = $0.15x - 00.014$ where x is % leaf-K). Although the linear relationships involving sap-K were significant, the strength of the relationships was relatively weak. Further statistical analysis with more data, partitioning data into crop growth stages, and/or examining alternative methods of measuring the sap K are needed before sap can be used to assess soybean K nutrition. Rosen et al. (1996) reported that diluted sap provided stronger relationships for K concentration than undiluted sap. However, the need to dilute sap increases the complexity of the measurement and opportunity for error, especially for making in-field measurements.

Practical Applications

Preliminary information regarding a rapid method of assessing soybean K nutritional status using a handheld instrument was successful in showing the general trend for sap-K to decline across time and differences among K rates. Undiluted petiole sap-K concentrations were more variable than the traditional plant tissue analysis methods, but it has the potential advantage of being done in the field and providing a rapid and economical indication of the plant's K status. Additional research will show whether the rate of petiole sap-K concentration decline across time is predictable and uniform across research locations.

Acknowledgements

Research was funded by the Soybean Check-off Program administered by the Arkansas Soybean Promotion Board, Rice Check-off Program administered by the Arkansas Rice Research and Promotion Board, Fertilizer Tonnage Fees, and the University of Arkansas System Division of Agriculture. A similar report was published in Research Series 642: Wayne E. Sabbe Arkansas Soil Fertility Studies 2016 (http://arkansas-ag-news.uark.edu/pdf/642.pdf).

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Table 1. Selected soil test information for four sites used for evaluating petiole sap-K trends across time.

Site [a]	Trial [b]	K Rate	pH	P	K	Ca	Mg
		lb K_2O/acre		----------------ppm----------------			
Pine Tree	PTRS-LTK	0	8.0	35	60	2720	544
		40	7.9	35	64	2586	545
		80	7.9	33	85	2322	511
		120	8.0	33	92	2616	541
		160	7.9	31	111	2352	515
Pine Tree	PTRS-I10	0	7.6	13	64	1664	298
Pine Tree	PTRS-F3	0	8.1	10	46	2022	324
Rice Research	RREC-LTK	0	5.4	44	85	998	109
		40	5.5	41	97	987	108
		80	5.3	43	111	928	103
		120	5.3	41	123	898	97
		160	5.4	44	148	920	99

[a] Pine Tree = University of Arkansas System Division of Agriculture's Pine Tree Research Station near Colt, Ark.; RREC = Rice Research and Extension Center, Stuttgart, Ark.

[b] LTK = Long-Term Potassium, and I-10 and F3 are abbreviations for field names.

Table 2. Planting date, sample dates and average soybean growth stage when tissue samples were collected for petiole sap-K extraction at four fields in 2016.

		Field			
Event	Growth Stage [a]	PTRS-LTK [b]	PTRS-I10	PTRS-F3	RREC-LTK
		---------------------Month/day -----------------------			
Plant date	--	May 11	May 7	May 5	May 17
Sample 1	R2	July 12	--	--	July 12
Sample 2	R2-3	July 19	July 19	July 19	July 20
Sample 3	R2-4	July 26	July 27	July 26	July 26
Sample 4	R4-5	Aug 2	Aug 2	Aug 2	Aug 3
Sample 5	R5	Aug 10	Aug 10	Aug 10	Aug 10
Sample 6	R5.5	Aug 17	Aug 17	Aug 17	Aug 18

[a] The listed growth stage represents the stage range for all four sites.

[b] Pine Tree = University of Arkansas System Division of Agriculture's Pine Tree Research Station near Colt, Ark.; RREC = Rice Research and Extension Center, Stuttgart, Ark.; LTK = Long-Term Potassium, and I-10 and F3 are abbreviations for field names.

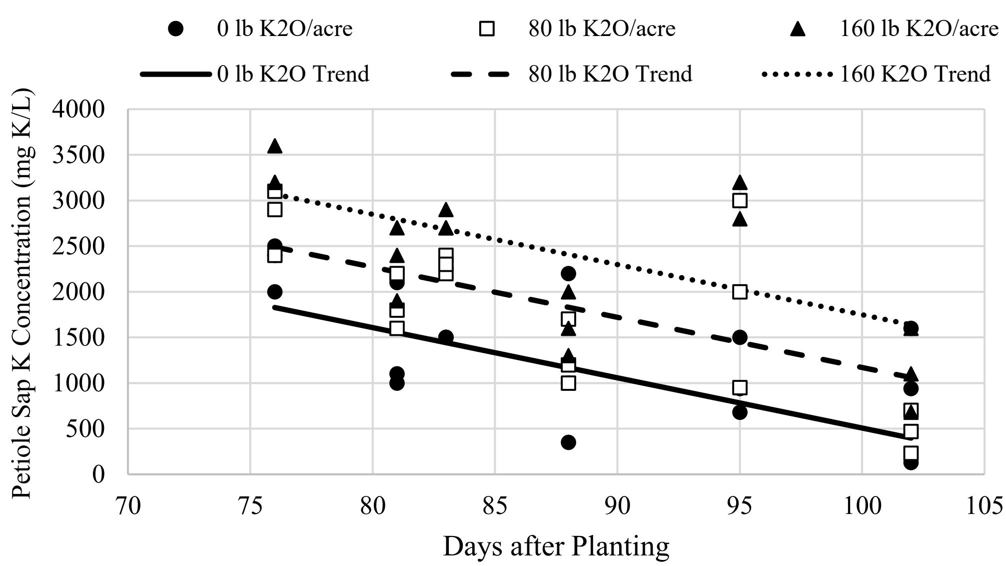

Fig. 1. Petiole sap-K concentration during reproductive growth of soybean receiving three different annual fertilizer-K rates from a long-term trial at the University of Arkansas System Division of Agriculture's Pine Tree Research Station, near Colt, Ark. in 2016.

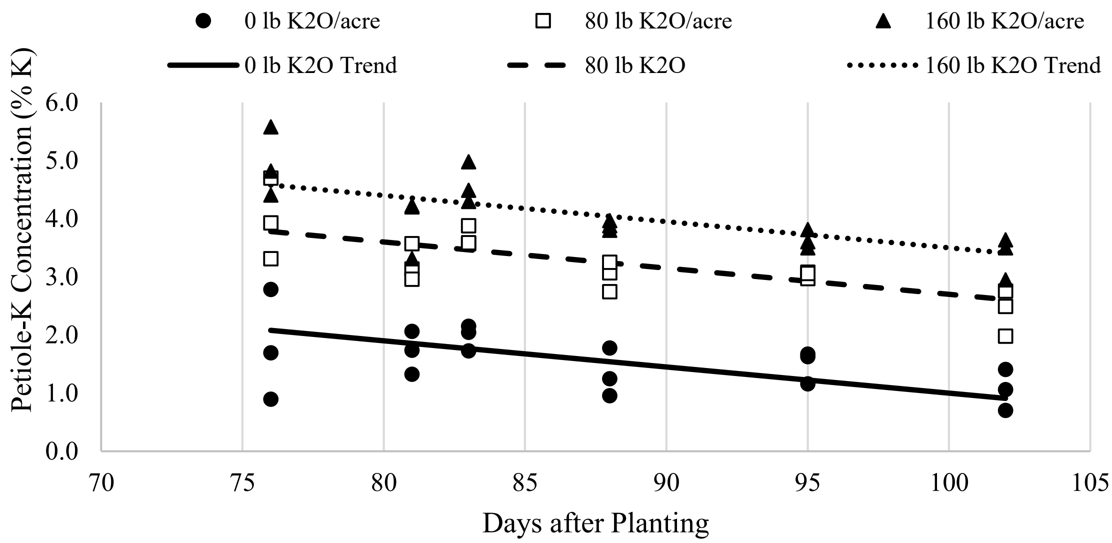

Fig. 2. Petiole-K concentration, as determined by traditional digestion and lab analysis, during reproductive growth of soybean receiving three different annual fertilizer-K rates from a long-term trial at the University of Arkansas System Division of Agriculture's Pine Tree Research Station, near Colt, Ark. in 2016.

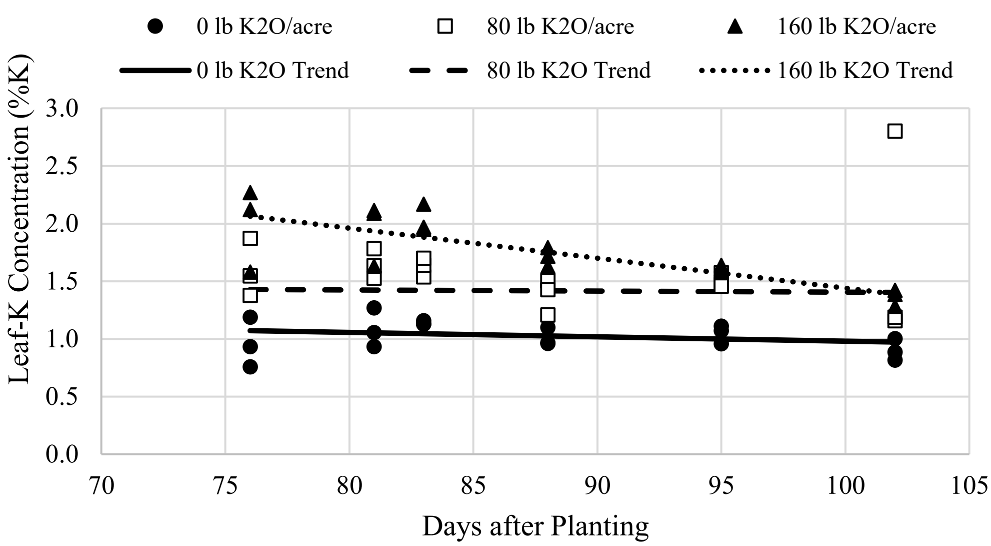

Fig. 3. Leaf-K, as determined by traditional digestion and lab analysis, concentration during reproductive growth of soybean receiving three different annual fertilizer-K rates from a long-term trial at the University of Arkansas System Division of Agriculture's Pine Tree Research Station, near Colt, Ark. in 2016.

Why Does Variability Exist among Variety Soybean Chloride Ratings?

D.D. Cox[1], N.A. Slaton[1], T.L. Roberts[1], T.L. Richmond[1], D.A. Sites[1], R.E. DeLong[1], and J. Hedge[2]

Abstract

Research is conducted annually to rate commercial soybean cultivars for their tolerance to chloride (Cl). The research objective was to examine the leaf-Cl concentration of a population of individual plants from several varieties to determine whether individual plants exhibit consistent Cl uptake (Cl inclusion or exclusion). Leaf tissue from 48 individual plants of 11 varieties representing maturity groups 4.7 to 5.3 were sampled and analyzed for Cl concentration. Leaf-Cl concentration means for each variety ranged from 221 to 3309 ppm Cl with standard deviations of 55 to 2092 ppm Cl indicating large differences in individual plant Cl concentrations for some varieties. Results show that many soybean varieties may be a mixture of plants with either the includer or excluder trait, which partially explains why Cl ratings from five-plant greenhouse assays are sometimes inconsistent.

Introduction

Research is conducted annually to assign a chloride (Cl) trait rating of includer or excluder to commercial soybean varieties. The soybean variety screening program in Arkansas assigns a rating to soybean varieties based on the leaf-Cl concentration of five individual plants grown in the greenhouse that are subjected to relatively high Cl concentrations and compared to known Cl-includer and Cl-excluder check varieties (Green and Conatser, 2014). The information from this screening method sometimes produces inconsistent annual ratings, which is frustrating and sometimes costly for growers that may need a Cl-excluding variety.

Arkansas soybean growers possess limited tools for dealing with Cl toxicity, which highlights the importance of accurate Cl-trait ratings. Our research objective was to examine the leaf-Cl concentration of a population of individual plants from several varieties to better understand whether individual plants within each variety exhibit consistent Cl uptake (Cl inclusion or exclusion). We anticipated that most soybean varieties would be a population of Cl includer and excluder plants rather than a pure population of plants that had similar leaf-Cl concentrations.

Procedures

A field trail was established at the University of Arkansas System Division of Agriculture's Pine Tree Research Station during 2016 on a Calloway silt loam. Selected mean soil chemical properties from composite soil samples (0 to 4-in. depth) included 6.3 pH, 88 µmhos/cm for soil electrical conductivity (1:2 soil weight to water volume mixture), 22 ppm Mehlich-3 P, 106 ppm Mehlich-3 K, 256 ppm Mehlich-3 Mg, 1161 ppm Mehlich-3 Ca, and 15.8 ppm water-soluble Cl. No fertilizers or soil amendments were added to the field prior to or during the growing season. The field had been fallow for at least two years.

The 11 varieties listed in Table 1 were selected for this study to represent maturity groups (4.7 to 5.3) commonly grown in Arkansas with some of the varieties having inconsistent Cl ratings (Table 1). From the most recent Cl ratings available for each variety, three varieties were rated as Cl-excluders, three were rated as mixed, and five were rated as Cl-includers. The Cl-ratings for the selected varieties may not be consistent with company ratings or ratings given in previous years of the Arkansas Cl screening trial.

Each variety was planted (130,000 seed/acre) in an 8-row strip that was 500 ft long with rows on the top center of beds spaced 30 inches apart. Beginning 100 ft inside the west border of the field, where polypipe was positioned for irrigation, three 50-ft blocks spaced 50 ft apart were established. Within each block at the V6 growth stage, 16 individual plants (48 plants/variety) from the two middle rows of each strip were identified with a flag and plants on either side of the flagged plant were pulled to avoid confusion about which plant was selected for the study. Soybean management in regard to pest control and irrigation closely followed the University of Arkansas System Division of Agriculture Cooperative Extension Service production guidelines. Soybean was furrow irrigated with surface-water from a nearby pond (61 mg Cl/L when sampled on 2 Aug. 2016).

At the R2-R3 growth stage, trifoliate leaf samples (leaf and petiole) were collected by removing the top four fully matured leaves and petioles from each plant. The sampled tissue was oven-dried, weighed, ground, extracted with water (Kalra, 1998), and extracts were analyzed for Cl concentration using inductively coupled plasma spectroscopy (Spectro Analytical Instruments Inc., Mahwah, N.J.).

The experiment was a strip trial design containing 11 varieties. The mean and standard deviation of leaf-Cl concentration were calculated for each variety using the MEANS procedure of SAS v. 9.4 (SAS Institute, Cary, N.C.). The MIXED procedure was used to determine if location in the field (block) had a significant effect on leaf-Cl concentra-

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tion to address the potential for spatial variability. For this analysis, variety and block were treated as fixed effects and significance was interpreted at the 0.10 level.

Leaf-Cl concentrations were allocated into six categories including low (<500 ppm), moderately low (501–1000 ppm), moderate (1001–2000 ppm), moderately high (2001–3000 ppm), high (3001–4000 ppm), and very high (>4000 ppm Cl) to represent the range of leaf-Cl concentrations. The Cl concentrations that define each category in this research are somewhat subjective (i.e., dependent on site and environment) and different Cl concentration ranges might be needed for an environment with different amounts of Cl. The percentage of plants within each Cl concentration category was summarized across all varieties and then by variety. Linear regression analysis was performed to evaluate the relationship between mean leaf-Cl concentration and individual leaf-Cl concentrations of each variety.

Results and Discussion

This study aimed to answer two questions: do individual, field-grown plants of a single variety have similar leaf-Cl concentrations, and, more comprehensively, why are variety Cl ratings inconsistent among years or screening times? The block main effect addressing leaf-Cl spatial variability was not statistically significant ($P = 0.33$) indicating that numerical differences in mean leaf-Cl concentration among blocks were due to the different behavior of individual plants (n =16) in each variety to accumulate Cl and not on the location in the field, Cl movement with irrigation water, or soil properties.

Leaf-Cl concentrations averaged across plants within a single variety ranged from 221 to 3309 ppm Cl (Table 1). Across the 11 varieties in our trial, the leaf-Cl categories in decreasing order of percentage of the total plant population followed the order of low, moderate, moderately high, moderately low, high and very high (Table 2). The distribution of plants among Cl concentration categories was clearly variety dependent (Table 2). The all-variety distribution does not likely represent that of all commercially available varieties since many of these 11 varieties were picked for specific reasons.

Pioneer 49T80R, rated as a Cl-excluder, had 100% of its plants with low leaf-Cl concentrations, which is behavior expected from a true Cl-excluding variety in this environment. Armor 47-R70 had over 90% of plants with leaf-Cl concentrations >1000 ppm Cl, which is consistent with the Cl-includer variety. Varieties labeled as mixed (Asgrow 5233, Progeny 4900RY, and Progeny 5333RY) had 43%, 85%, and 79% of plants with low leaf-Cl concentrations (<500 ppm) and 47%, 8%, and 17% of plants with leaf-Cl concentrations >1000 ppm, respectively. The remaining includer varieties (Armor 47-R13, Asgrow 4934, Dynagro S52RY75, and Pioneer 49T09BR) had no plants with low leaf-Cl concentrations (<500 ppm) and all, except Asgrow 4934, had >90% of the plants with leaf-Cl concentrations >1000 ppm. The two remaining excluder varieties (GoSoy 4914GTS and NK S48-D9) produced 13% and 50% of plants with leaf-Cl concentrations <500 ppm and 15% and 44% with >1000 ppm, respectively. The majority of the GoSoy 491GTS plants had moderately low Cl concentrations suggesting it behaved as a Cl-excluder.

A preliminary configuration for a new rating system was examined using plant mean leaf-Cl concentrations and Cl distribution data. We summarized the 11 varieties into 2 categories including the percentage of plants with low Cl (<500 ppm Cl) and plants having moderate and greater Cl concentrations (>1000 ppm Cl, Tables 1 and 2). The mean leaf-Cl concentration (dependent variable, Table 1) regressed against the percentage of plants having low leaf-Cl concentrations (independent variable, Table 2) showed a relatively weak relationship ($R^2 = 0.57$, not shown). However, the relationship between mean leaf-Cl concentration and the percentage of plants having moderate and higher leaf-Cl concentrations was positive, linear, and relatively strong (Fig. 1).

Based on the relationship in Fig.1, a preliminary rating system on a 1–10 scale could possibly be developed using composite leaf samples from field-grown variety trials. For example, varieties having less than 10% of its plants with leaf-Cl concentrations >1000 ppm for this field environment would be assigned a rating of 1 and represent a strong Cl-excluder (e.g., 2 = 11-20%, 3 = 21-30%, 4 = 31-40%, etc…). Additional research is needed to confirm the consistency of these results using more varieties and different locations.

Practical Applications

The results of our study showed that many soybean varieties may be a mixture of plants with either the includer or excluder trait and explains why Cl ratings are sometimes inconsistent. The ratio of includer to excluder plants in the population of a single variety likely influences the overall performance of the variety in the presence of high Cl concentrations and the mean leaf-Cl concentration of field grown plants appears to be well correlated with the percentage of Cl-including plants in the population. Our trial did not fully examine whether plants have a range of abilities to include or exclude Cl, but a wide range of leaf-Cl concentrations were measured. The fact that most varieties likely contain a mixture of includer and excluder plants may be the primary reason for a single variety having different Cl-trait ratings from the annual five-plant greenhouse screening. Research to characterize the ratio of includer and excluder plants of more varieties with different maturity groups and herbicide tolerance technologies is warranted and needed to develop a more robust and accurate Cl-trait rating system. The data from this trial will also provide insight as to how many plants of each Cl rating (includer, excluder and mixed) varieties are needed to provide reasonably accurate assessments of the population.

Acknowledgements

Research was funded by the Soybean Check-off Program, administered by the Arkansas Soybean Promotion Board, Fertilizer Tonnage Fees, and the University of Arkansas System Division of Agriculture. Special thanks to all the companies providing seed for the field trial (Armor, Asgrow, DynaGro, Pioneer, and Syngenta) and staff at the Pine Tree Research Station. A similar report was published in Research Series 642: Wayne E. Sabbe Arkansas Soil Fertility Studies 2016 (http://arkansas-ag-news.uark.edu/pdf/642.pdf).

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Ross, W.J., D.G. Dombek, J.A. Still, R.D. Bond, J.K. Norsworthy, T.L. Kirkpatrick, K. Rowe, T. Faske, M. Emerson, and M. Conatser. 2015. Soybean update: 2015 soybean performance results for early planted, full-season & double-crop production systems in Arkansas. Univ. of Ark. Coop. Ext. Serv. Little Rock, Ark.

Table 1. Varieties, chloride (Cl)-rating category, leaf Cl means and standard deviations, and percentage of plants in two categories for each variety from the field trial conducted at University of Arkansas System Division of Agriculture's Pine Tree Research Station in 2016. Chloride ratings as denoted by Ross et al. (2014, 2015).

Variety	Cl Rating (Cl Screening Trials)			Leaf-Cl Concentration		Percentage of Plants	
	2013	2014	2015	Mean	SD[a]	<500 ppm	>1000 ppm
				-------ppm Cl-----		--------------%--------------	
Pioneer P49T80R	Excluder	Mixed	Excluder	221	55	100	0
Progeny P4900RY	.	Excluder	Mixed	400	670	85	8
Progeny P5333RY	Excluder	Excluder	Mixed	437	522	17	17
GoSoy 4914GTS	Mixed	Excluder	Excluder	759	253	13	15
NK S48-D9	.	Includer	Excluder	875	837	50	44
Asgrow AG5233	Mixed	Mixed	Mixed	1045	906	43	47
Asgrow AG4934	Includer	Includer	Includer	1319	456	0	66
Armor 47-R70	.	.	Includer	1693	513	0	96
Armor 47-R13	Includer	Includer	.	2225	1124	0	94
Pioneer P49T09BR	.	.	Includer	2350	1397	0	100
Dynagro S52RY75	.	Mixed	Includer	3309	2092	0	100

[a] SD, Standard deviation.

Table 2. Distribution of leaf-chloride (Cl) concentration using all varieties from the 2016 soybean chloride population trial conducted at the University of Arkansas System Division of Agriculture's Pine Tree Research Station in 2016.

	Leaf Cl Concentration Range					
Variety	Low 0–500 ppm	Moderately Low 501–1000 ppm	Moderate 1001–2000 ppm	Moderately High 2001–3000 ppm	High 3001–4000 ppm	Very High >4000 ppm
	---% of plants					---
Pioneer 49T80R	100	0	0	0	0	0
Progeny 4900 RY	85	7	0	6	2	0
Progeny 5333RY	79	4	15	2	0	0
GoSoy4914GTS	13	72	15	0	0	0
NK S48-D9	50	6	33	11	0	0
Asgrow AG5233	43	11	32	13	2	0
Asgrow AG4934	0	34	62	4	0	0
Armor 47-R70	0	4	71	23	2	0
Armor 47-R13	0	6	50	27	8	8
Pioneer 49T09BR	0	0	44	48	4	4
Dyna-Gro S52RY75	0	0	21	44	17	18
All Varieties	34	13	31	16	3	3

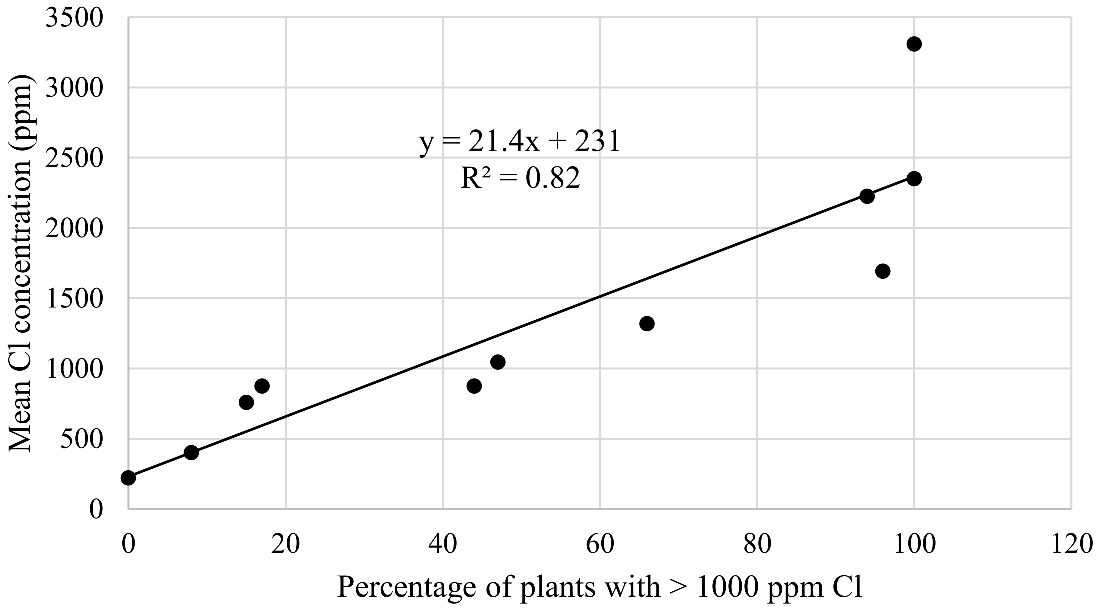

Fig. 1. Mean leaf chloride (Cl) concentration (n = 48) regressed across percentage of plants with leaf-Cl concentrations greater than 1000 ppm Cl. Data taken from soybean Cl population trial conducted at the University of Arkansas System Division of Arkansas's Pine Tree Research Station in 2016.

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